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Vegetative filter strip buffer effects on runoff, sediment, and nutrient losses from a grazing and windrow composting site

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Vegetative filter strip buffer effects on runoff, sediment, and nutrient losses from a grazing and windrow composting site

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ABSTRACT

The dissertation Chapter 3 grazing/vegetative filter strip (VFS) buffer research project quantifies the effects of grazing management practices and VFS buffers on losses of runoff (RO) with total solids (TS), nitrate-nitrogen (NO_3-N), ortho-phosphorus (PO_4-P), and total-phosphorus (TP) during natural rainfall events. Runoff data were collected from 12 events during 2001-2003 at an Iowa State University research farm in central Iowa, USA. Three grazing management practices (5.1-cm [2-in] continuous grazing [con], 5.1-cm [2-in] rotational grazing [rot], and no grazing [ng] control) and three VFS buffers (paddock area:buffer area ratios of 5:1, 10:1, and no buffer [NB] control) comprised nine treatment combinations. The nine treatments were replicated in three 2.75 ha (6.8 ac) plot areas for a total of 27 runoff collection units distributed in a randomized complete block design. The plot areas were on uneven terrain with up to 15 percent slopes and consisted of approximately 100 percent smooth brome (*Bromus inermis* Leyss.). Average paddock and VFS buffer plant tiller densities were approximately 62M and 93M tillers/ha, respectively. Results from 2001 and 2002 show no significant differences ($p < 0.10$) in average losses of RO, TS, NO_3-N, PO_4-P, and TP among the nine treatment combinations. The 2003 results also show no significant differences ($p < 0.10$) in losses of RO, TS, PO_4-P, and TP. However, the 2003 results indicate significantly higher ($p < 0.01$) losses of NO_3-N from "10:1ng" treatments compared to all other treatment combinations and reflect a possible tendency towards elevated losses in some "ng" treatments from "con" treatments in 2001 and 2002. Runoff analysis results indicate grazing management practices did not significantly affect runoff losses ($p < 0.10$). These results and other research findings suggest the relatively higher 2003 event precipitation, antecedent moisture, concentrated surface flow conditions, dense cool-season smooth brome, and forage nutrient cycling processes may have contributed to the potential shift of elevated losses to the non-grazed "ng" treatments. Results also suggest warm-season grasses like switchgrass (*Panicum virgatum* L.) could be incorporated into certain paddock areas in a rotational grazing management program to improve grazing efficiency and reduce RO and contaminant losses. The dissertation

Chapter 4 windrow composting/VFS buffer study quantifies the effects of windrow composting practices and VFS buffers on losses of runoff (RO), runoff percent of rainfall (RO%), total solids (TS), nitrate-nitrogen (NO_3-N), ortho-phosphorus (PO_4-P), and total-phosphorus (TP) during natural rainfall events. Runoff data from six events were collected during June-July (early season) and August-September (late season) 60-day composting periods from 2002-2004 at an Iowa State University research farm near Ames, central Iowa, USA. Runoff treatments were comprised of three compost windrow:VFS buffer area ratios that included 1:1, 1:0.5, and 1:0 (no buffer) control. The 1:1 and 1:0.5 area ratios represented a 6 m x 23 m (20 ft x 75 ft) fly ash composting pad area compared to VFS buffer areas of equal and one-half size, respectively. All treatments had three replications for a total of nine runoff plots distributed in a randomized complete block design. Results from the study indicate significantly higher levels ($p < 0.05$) of RO, RO%, TS, NO_3-N, PO_4-P, and TP from the 1:0 control plots compared to the 1:1 and 1:0.5 plots. Results also show the 1:1 and 1:0.5 VFS buffer treatments were not significantly different ($p < 0.05$). Average runoff loss reductions from the 1:1 and 1:0.5 plots were 98 and 93 percent, respectively, compared to the 1:0 control plots. These results reflect the effectiveness of VFS buffers for reducing runoff and contaminant losses from a windrow composting site. Compost nutrient mass balance analysis results indicate 26-41 percent of PO_4-P was lost from the compost windrows during the 2004 composting periods. However, only 0.1-0.4 percent of PO_4-P was lost to runoff from the 1:0 control plots. We hypothesize the significantly lower PO_4-P losses in runoff may be attributed to potential chemical and physical effects of the fly ash composting pad material. The dissertation Chapter 5 hydrologic modeling study calibrated and validated a hydrologic model for predicting runoff volume losses from a windrow composting site with VFS buffers. The site also included a composting pad surface constructed of fly ash obtained from a local coal-fired power generating station. Observed runoff and physical attribute data from six rainfall events during 2002-2004 at a central Iowa windrow composting research site were used in the model evaluation. These data included average runoff volumes from three compost windrow:VFS buffer area ratio treatments (1:1, 1:0.5, and 1:0 [no buffer] control), each replicated to comprise

a total of nine plots. Calibration simulations indicated good agreement of simulated runoff data to observed data for all 1:1, 1:0.5, and 1:0 (no-buffer control) VFS buffer treatments. The 1:0 (control) treatment plots also indicated good data agreement for all calibration and validation simulations. However, validation simulations resulted in overpredictions for the 1:1 and 1:0.5 VFS buffer runoff volumes that were most significant in the 2004 late rainfall events period. Results from this initial study with limited data indicated that alternatives to soils data-derived VFS buffer surface infiltration and runoff functions should be considered to potentially improve model prediction accuracy. These results and other research findings suggest that possibly the fly ash composting pad material and age of the research site may have contributed to the overpredicted 1:1 and 1:0.5 VFS buffer runoff validation simulation results.

CHAPTER 1: GENERAL INTRODUCTION

Introduction

Surface runoff containing nonpoint source (NPS) pollution continues to be a serious problem for the nation's water resources. The 2002 national water quality inventory shows that since 2000, 39 percent of assessed stream miles, 45 percent of assessed lake acres, and 51 percent of assessed estuary acres are impaired (EPA, 2003). The national inventory identifies nutrients, siltation, metals, and pathogens as the leading causes of impairment. State inventories of water quality indicate agricultural activities of crop production, livestock operations, pastures, and rangeland impact 18 percent of the total river and stream miles assessed and 48 percent of impaired rivers and streams (EPA, 2002).

Livestock grazing of pastures can significantly affect the soil-water environment (Schepers and Francis, 1982; Owens et al., 1989; Nelson et al., 1996; Krzic et al., 2006). Grazed pastures can contribute phosphorus (P) to surface waters (Downing et al., 2000), and have higher P losses than non-grazed pastures (Gillingham and Thorrold, 2000). Nitrogen (N) losses from agricultural/grazing fields to surface and subsurface waters also have been documented (Madramootoo et al., 1992; Sauer et al., 2000; Stout et al., 2000). Various studies have indicated that N and P losses from continuous grazing pastures are generally higher than rotational grazing and non-grazed pastures (Ritter, 1988; Mathews et al., 1994). Although livestock grazing can adversely impact the soil-water environment, Sharpley and Syers (1976) determined that P transport due to grazing animals was significantly less than P fertilizer addition. Nash et al. (2000) found that cattle did not mobilize large stores of available P relative to P fertilization. The grazing method of well-managed pastures may have little effect on short-term soil nutrient distribution, especially when grazing occurs during the warmer months when temperatures are high (Mathews et al. 1994).

While grazing management practices can affect runoff, erosion, and nutrient losses from pasture systems, vegetative characteristics of different forage species also can influence the surface hydrology of pastures. Self-Davis et al. (2003) researched various forage plant species and cover effects from small vegetated plots and determined that tall fescue (*Festuca arundinacea* Schreber.) significantly reduced runoff and increased infiltration. The inclusion of warm-season grass types into a rotational grazing sequence can improve vegetation quality and grazing efficiency (Mitchell et al., 1998; Moore et al., 2004; Roberts and Kallenbach, 2006) and may reduce runoff, sediment, and nutrient losses in areas with slopes less than 4 percent (Broadmeadow and Nisbet, 2004).

Windrow composting consists of placing manure and other raw materials in long narrow piles or windrows which are agitated or turned on a regular basis (Rynk et al., 1992). Studies have shown that composted manure is less hazardous to the environment (Eghball and Power, 1999; Vervoort et al., 1998) and much of the mineral N is converted to more stable organic forms (Rynk et al., 1992). Compost also has been shown to significantly reduce P in runoff from road construction sites (Jurries 2003) and nitrate (NO_3-N) leaching relative to conventional fertilizers (Maynard, 1993). However, one of the disadvantages of composting is nutrient loss during the composting process, which can occur through leaching, runoff, and volatilization (Christensen, 1983, 1984; Richard and Chadsey, 1994; Eghball et al., 1997; Tiquia et al., 2000). Mass balance analysis results of a composting site indicated 20-60 percent losses of N, P, and potassium (K) during composting processes (Tiquia et al., 2002), of which the most significant losses were runoff and leachate (Garrison et al., 2001). Seymour and Bourdon (2003) reported concentrations of NO_3-N, ortho-P (PO_4-P), and K were highest in leachate compared to runoff samples from compost windrows under natural rainfall conditions. Wilson et al. (2004) reported that approximately 68 percent of rainfall incident on saturated compost windrows from both natural and simulated rainfall events resulted in runoff.

Several researchers have investigated the capabilities of fly ash to reduce PO_4-P concentrations in surface runoff (Dou, et al., 2003; Boruvka and Rechcigal, 2003; Lau et al., 2001; Brauer et al., 2005; DeLaune et al., 2006; Penn and Bryant, 2006). They found that fly ash and some other liming materials reduced PO_4-P concentrations in runoff up to 84 percent from calcium oxide reactions converting soluble P to a more stable fraction that is less vulnerable to potential losses with runoff. Based on compost nutrient mass balance and runoff nutrient analysis results, this dissertation research also investigated the potential of a compost pad constructed of fly ash material to reduce the PO_4-P concentration and total losses in surface runoff from a windrow composting site.

Vegetative filter strip (VFS) buffers have been promoted as a best management practice (BMP) for reducing runoff, sediment, and nutrient losses on pastures and agricultural crop land. VFS buffers are bands of vegetation located downslope of cropland, livestock grazing areas, and other potential sources of surface runoff and contaminants (Dillaha et al., 1989). These VFS buffers provide erosion control and filter nutrients, pesticides, sediment, and other pollutants from agricultural runoff by reducing the sediment carrier and through interception-adsorption, infiltration, and degradation of pollutants dissolved in water. Various researchers have reported on the effectiveness of VFS buffers in treating agricultural runoff (Snyder et al., 1998; Smith et. al, 2000; Bharati et al., 2002; Gharabaghi et al., 2001; Koelsch et al., 2006). VFS buffers also have been suggested as a best management practice for removing water pollutants from surface runoff (Dillaha et al., 1989; Mickelson and Baker, 1993; Gilley et al., 2000). A VFS buffer study by Patty et al. (1997) showed a reduction of 47-100 percent and 22-89 percent of NO_3-N and total P, respectively, in runoff. However, Dosskey et al. (2002) modeled the effects of concentrated flow through vegetation and how this can reduce the efficacy of VFS buffers. Several researchers also have generated qualitative reports regarding the stiff stems and extensive root systems of warm-season grass species that provide more effective VFS buffer vegetation than some cool-season grasses for reducing sediment, and nutrient losses with runoff (Schultz et al., 1997; Lee et al., 1998; Broadmeadow and Nisbet, 2004). This dissertation research provided a quantitative evaluation of the impact of vegetative type on the effectiveness of VFS buffers to mitigate surface runoff.

Hydrologic models have been used for over 30 years to simulate sediment and nutrient transport in surface runoff through VFS buffers (Tollner et al., 1976; Delgado et al., 1992; Srivastava et al., 1998). However, few reports exist regarding the use of hydrologic models for predicting runoff losses from windrow composting sites. Governo (2001) developed a spreadsheet-based computer program to assist in the design phase of windrow composting facilities, but did not include a hydrologic modeling component.

Tollner and Das (2004) evaluated hydrologic models that included the NRCS Curve Number method for predicting runoff from a yard waste windrow composting site. Although this study described a hydrologic modeling approach for windrow composting sites, it did not include a runoff modeling function for VFS buffers. Considering the level of concern regarding surface runoff and NPS pollution, the development of an accurate hydrologic model with a VFS buffer component would be an important step in protecting stream and other water bodies from sediment and nutrient contaminants. This dissertation study included an initial evaluation of a hydrologic model for a windrow composting site with VFS buffers.

Dissertation Organization

This dissertation includes the candidate's original work on determining the effects of VFS buffers on runoff from a grazing and windrow composting site. This dissertation also is comprised of three separate manuscripts in the required format for refereed journal publications.

The first manuscript entitled "Grazing and vegetative filter strip buffer effects on sediment and nutrient losses with runoff" was prepared for submission to the journal *Transactions of the American Society of Agricultural and Biological Engineers*. The primary researcher and author of this manuscript is David F. Webber, graduate student, Department of Agricultural and Biosystems Engineering, Iowa State University, Ames, Iowa. Steven K. Mickelson, Associate Professor, Department of Agricultural and Biosystems Engineering, Iowa State University, provided overall guidance in data interpretation and manuscript preparation and is the corresponding author. Syed I. Ahmed, former postdoctoral research associate, Department of Agricultural and Biosystems Engineering, Iowa State University provided data collection early in the project. James L. Russell, Professor, Department of Animal Science, Iowa State University, contributed forage and livestock data. Wendy J. Powers, former Associate Professor, Department of Agricultural and Biosystems Engineering, Iowa State University, provided assistance in manuscript preparation. Richard C. Schultz, Professor, Department of Natural Resource Ecology and Management, Iowa State University, provided assistance in manuscript preparation. John L. Kovar, soil scientist, National Soil Tilth Lab, Agricultural Research Service, U.S. Department of Agriculture, Ames, Iowa, provided assistance in manuscript preparation.

The second manuscript entitled "Sediment and nutrient losses with runoff from a windrow composting site with vegetative filter strip buffers" was prepared for submission to the *Journal of Soil and Water Conservation*. The primary researcher and author of this manuscript is David F. Webber, graduate student, Department of Agricultural and Biosystems Engineering, Iowa State University, Ames, Iowa. Steven K. Mickelson, Associate Professor, Department of Agricultural and Biosystems Engineering, Iowa State University, provided overall guidance in data interpretation and manuscript preparation and is the corresponding author. Thomas L. Richard, former Associate Professor, Department of Agricultural and Biosystems Engineering, Iowa State University, supervised windrow composting aspects of the project. Hee-Kwon Ahn, Assistant Scientist, Department of Agricultural and Biosystems Engineering, Iowa State University, provided composting data.

The third manuscript entitled "Hydrologic modeling of runoff from a windrow composting site with vegetative filter strip buffers" was prepared for submission to the journal *Composting Science and Utilization*. The primary researcher and author of this manuscript is David F. Webber, graduate student, Department of Agricultural and Biosystems Engineering, Iowa State University, Ames, Iowa. Steven K. Mickelson, Associate Professor, Department of Agricultural and Biosystems Engineering, Iowa State University, provided overall guidance in data interpretation and manuscript preparation and is the corresponding author. Larry W. Wulf, Laboratory Technician, Veterinary Diagnostics Laboratory, Iowa State University, provided the hydrologic computer model for the project. Thomas L. Richard, former Associate Professor, Department of Agricultural and Biosystems Engineering, Iowa State University, supervised windrow composting aspects of the project. Hee-Kwon Ahn, Assistant Scientist, Department of Agricultural and Biosystems Engineering, Iowa State University, provided composting data.

Each manuscript includes an abstract, introduction, materials and methods, results and discussion, summary and conclusions, and references sections. A general introduction and literature review chapters precede the three manuscripts. The three manuscripts are followed by a general conclusion chapter. References for the general introduction and general conclusions chapters appear at the end of each of these chapters.

Research Objectives

The overall objective of this research was to determine the effects of VFS buffers on runoff, sediment, and nutrient losses from a grazing and windrow composting site. The specific objectives were as follows:

1. Evaluate the effects of grazing management practices and VFS buffers on runoff, sediment, and nutrient losses
2. Evaluate the effects of windrow composting and VFS buffers on runoff, sediment, and nutrient losses
3. Calibrate and validate a computer hydrologic model to predict runoff volume from a windrow composting site with VFS buffers

Study Site Descriptions

Iowa State University Rhodes Research Farm Site

This study was conducted during 2001-2003 at Iowa State University's Rhodes Research and Demonstration Farm in southwest Marshall County, central Iowa, USA (41° 53.615' N, 93° 12.073' W). The study site total area was 8.25 ha (20.4 ac) comprised of three plots, each approximately 2.75 ha (6.8 ac). Each plot was selected on uneven terrain with slopes up to 15 percent in a smooth brome (*Bromus inermis* Leyss.) pasture at the research site. Vegetation species in both paddocks and VFS buffer areas were approximately 100 percent grasses and a trace of mixed broadleaf species. The average tiller populations for the paddocks and VFS buffers were estimated to be 62M and 93M tillers/ha, respectively. Percent of tiller species and population was determined using a method from Arora et al. (2003). Each plot was subdivided into five 0.4 ha (1 ac) paddocks and fenced. The major soil association at the research site is the Downs-Gara association with silty and loamy soils formed on upland loess and glacial till. The dominant soil at the research site is Downs silt loam, a fine-silty, mixed, mesic Mollic Hapludalfs (Oelmann, 1981). After initial soil sampling in the spring of 2001, P was applied to the three plot areas within the recommended optimum range of 11-15 ppm P_2O_5. Sandbags were placed around the perimeter of the plot areas and between each paddock to prevent cross-contamination between adjacent paddocks from runoff by rainfall events.

Iowa State University Dairy Teaching Farm Site

The study site was located at the Iowa State University Dairy Teaching Farm in Ames, Story County, central Iowa, USA (42° 00.564' N, 93° 39.267' W). The study site total area was 0.25 ha (0.62 ac) comprised of nine plots, each 6 m x 46 m (20 ft x 150 ft). The research plot area was selected on uneven terrain with an average slope of 5 percent. Dominant vegetation included approximately 75 percent smooth brome (*Bromus inermis* Leyss.), 25 percent switchgrass (*Panicum virgatum* L.), and a trace of mixed broadleaf species. Smooth brome occupied approximately 75 percent of each 1:1 VFS buffer plot, primarily in the upslopes, and approximately 100 percent of each 1:0.5 VFS buffer plot in the upslopes. Switchgrass in the downslopes occupied approximately 25 percent of each 1:1 VFS buffer plot, but only a trace was observed in the 1:0.5 VFS buffer plots. The average tiller population for VFS buffers was estimated to be 2.7M tillers/ha. Tiller population was determined using a method from Arora et al. (2003). The major soil association at the research site is the Clarion-Webster-Nicollet association, with the minor soil association of Hayden-Lester-Storden in the area. All soils were formed in glacial till and local alluvium from till, with Clarion loam (a fine-loamy, mixed, mesic Typic Hapludolls) the dominant soil at the research site (Dewitt, 1984). The upslope composting pad surface area of the site was comprised of fly ash, a by-product of combustion from coal-fired power plants provided by Alliant Energy, Inc., Madison, Wisconsin, USA. The 0.13 ha (0.32 ac) composting pad area was constructed by machine grading to approximately a 2 percent slope, and fly ash was hydro-compacted to a depth of 30.48 cm (12 in).

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CHAPTER 2: LITERATURE REVIEW

General Background

Grazing Site Sediment and Nutrient Losses with Runoff

Livestock grazing of pastures can significantly affect the complex soil-water environment (Sharpley and Syers, 1976; Schepers and Francis, 1982; Cooper and Thomsen, 1988; Owens et al., 1989; Smith, 1992; Nelson et al., 1996; Haygarth and Jarvis, 1997; Carpenter et al., 1998; Butler, 2004; Krzic et al., 2006). Grazed pastures can be key contributors of phosphorus (P) to surface waters (Downing et al., 2000), and have higher P losses than non-grazed pastures (Gillingham and Thorrold, 2000). Addiscott et al. (2000) showed that significant P losses could occur from cultivated fields via subsurface drains. Nitrogen (N) losses from agricultural/grazing fields to surface and subsurface waters also have been documented (Madramootoo et al., 1992; Stout et al., 2000). Other studies have shown that N and P losses from continuous grazing pastures are higher than rotational grazing pastures (Ritter, 1988; Mathews et al., 1994). Although cattle grazing can negatively affect runoff water quality, Nash et al. (2000) found significant P levels in runoff corresponded to P fertilizer application levels.

Various researchers have reported on the effectiveness of vegetative filter strip (VFS) buffers in treating agricultural runoff (Doyle et al., 1977; Young et al., 1980; Lee et al., 1989; Magette et al., 1989; Chaubey et al., 1994; Edwards et al., 1996; Robinson et al., 1996; Snyder et al., 1998; Eghball et al., 2000; Smith et al., 2000; Tate et al., 2000; Bharati et al., 2002; Gharabaghi et al., 2001; Koelsch et al., 2006). VFS buffers also have been suggested as a best management practice (BMP) for removing water pollutants from surface runoff (Dillaha, 1989; Dillaha et al., 1989; Mickelson and Baker, 1993; Gilley et al., 2000). A VFS buffer study by Patty et al. (1997) showed a reduction of 47-100 percent and 22-89 percent of NO_3-N and total P, respectively, in runoff water. Other VFS buffer studies included determining optimal buffer length (Srivastava et al., 1996; Lim et al., 1998) and the efficacy of VFS buffers in removing fecal coliform and other bacterial pathogens from runoff (Lim et al., 1998; Fajardo et al., 2001; Roodsari et al., 2005). Some recent reports also document the effects of riparian VFS buffers on streambank erosion adjacent to grazed pastures (Zaimes et al., 2004), computer modeling of VFS runoff (Munoz-Carpena, et al., 1993, 1999; Zegre, 2003), and the establishment of VFS buffers using precision information (Dosskey et al., 2005).

Researchers also have documented the effects of various vegetation types on livestock grazing areas and how certain grass species affect surface runoff flow. Smooth brome is a strongly rhizomatous, sod-forming perennial grass that was introduced from Eurasia in 1884 (USGS, 2006) and was reported to be the most agronomically important grass species (Hitchcock, 1950). This aggressive cool-season grass is resistant to temperature extremes and drought due to its highly developed root system and grows best on deep, well-drained silt or clay loam soils (Roberts and Kallenbach, 2006). Now considered to be naturalized over most of North America, smooth brome has escaped throughout its range and is often considered a highly competitive weed of roadsides, forests, prairies, fields, lawns, and lightly disturbed sites (USGS, 2006). Cool-season grasses, such as brome and fescue, tend to lay over in runoff flow, making them less suitable for VFS buffers, compared to stiff-stemmed, warm-season species like switchgrass (Schultz et al., 1997).

The literature cited in this manuscript mainly focuses on documenting the effects of livestock grazing and VFS buffers on runoff water quality. However, grazing and VFS buffer effects vary with different field conditions due to the complex soil-water environment. Consequently, the objective of this research is to quantify the effects of various grazing management practices and VFS buffer treatments on total losses of total solids (TS), nitrate-nitrogen (NO_3-N), ortho-phosphorus (PO_4-P), and total-phosphorus (TP) in surface runoff during natural rainfall events. Critical consideration was given to the effects of vegetation type and density on surface runoff flow and contaminant transport.

Windrow Composting Site Sediment and Nutrient Losses with Runoff

Most large-scale livestock manure management systems produce significant volumes of manure, requiring storage and treatment. Many municipal and urban activities also produce solid waste volumes that require treatment. Livestock and municipal wastes are compatible with composting. Composting systems generally are comprised of four groups that include passive composting, windrows, aerated static piles, and a group known collectively as in-vessel (bin, silo, bio-reactor, or rotating drum) composting (Rynk et al., 1992; Card and Davis, 2004). This dissertation research project involved the use of "dynamic" compost windrows, indicating they were turned periodically throughout the composting process with special compost turning equipment.

Windrow composting systems can accommodate large volumes of diverse wastes, including yard trimmings, grease, liquids, and animal byproducts (USEPA, 2004; Manitoba Agriculture, Food, and Rural Initiatives, 2004). Windrow composting systems are used by the US Army and other military branches to effectively and economically remediate soil contaminated by high explosives (USAEC, 2003) and to compost other organic waste materials (Joint Service Pollution Prevention Opportunity Handbook, 2003). Finished compost products have traditionally been used as a soil amendment, including a liquid form known as "compost tea" that is derived from soaking compost in water. Recent research has shown that compost can be applied to bare soil conditions to reduce erosion and improve vegetation establishment in road right-of-way projects (Jurries, 2003; Persyn et al., 2004).

Windrow composting is an effective bioconversion process for managing these wastes, reducing odor, stabilizing nutrients, and generating an easily stored product. By combining livestock manure and municipal waste sources, overall improvement of the composting attributes is possible. While many of these benefits of composting are well known, few reports exist that document water quality impacts at windrow composting sites. Also, public knowledge and understanding of composting and water quality impacts need improvement. In particular, the fate of nutrients needs to be better understood and addressed in the outdoor windrow systems that predominate in municipal and agricultural composting applications.

Recent mass balance analysis results of a composting site indicated 20-60 percent losses of N, P, and K during composting processes (Tiquia et al., 2002), of which the most significant loss appears to be as runoff and leachate (Garrison et al., 2001).

Seymour and Bourdon (2003) also reported that concentrations of nitrate-N, dissolved-P, and K were highest in leachate compared to runoff samples from compost windrows under natural rainfall conditions. Based on these results, the demonstration of low-cost and effective water protection measures that include vegetative filter strip (VFS) buffers in this research is an important component in the development of environmentally sound windrow composting facilities.

The management and utilization of livestock manures continue to pose hazards to the quality of receiving streams and lakes. In the US, two-thirds of the total beef cattle feeding is practiced in the central and southern Great Plains (Kraus, 1991). Handling of manure produced in large feedlots and dairies is a significant environmental problem for water, air, and land pollution. Manure is an excellent source of organic matter and plant nutrients, but even under proper management, conventional manure utilization can have negative impacts. Land application of manure to agricultural fields can elevate runoff concentrations of nutrients such as nitrogen (N), carbon (C), and phosphorus (P) (Westerman et al., 1987; Edwards and Daniel, 1993; Heathwaite and Jones, 1998). Surface runoff of nutrients from agricultural fields is a major source of water pollution in surface waters in the US (Parry, 1998).

Several best management practices (BMPs) have potential to reduce nutrients in surface runoff. Composting and VFS buffers are two effective practices to reduce nutrient losses from runoff in cultivated fields. Composting converts much of the mineral nitrogen to more stable organic forms (Rynk et al., 1992), reducing leaching and runoff losses after land application. Jurries (2003) reported that all types of vegetative compost can greatly reduce total-P and heavy metals (except zinc) in runoff. This is mainly due to the reduction in particulate material in the runoff, including the colloidal suspensions (Dennis Jurries, 2005, personal comm.). VFS buffers also have been shown to reduce nutrient and sediment losses in a range of agricultural settings, including crop fields and feedlots. This project combined windrow composting and VFS buffer systems at a single high-visibility demonstration site, the Iowa State University (ISU) Dairy Teaching Farm in Ames, Iowa.

Composting is attracting increasing attention as a solution to several manure problems. It produces a stabilized product that can be stored or spread with little odor, reduces disease pathogens and weed seeds, and reduces manure volume and weight (Sweeten, 1988; Miller, 1991; Rynk et al., 1992; Naylor, 1996; Wiese et al., 1998; Eghball and Power, 1999; Rynk and Richard, 2001). Some studies also have compared the effects of composted and uncomposted manure applications on crop yield. The studies showed that fresh and composted manure produced similar crop yields, while composted manure was less hazardous to the environment (Eghball and Power, 1999; Vervoort et al., 1998). Other studies have shown that windrow composting systems function more efficiently when compost moisture and air-filled porosity conditions are properly managed (Richard et al., 2002; Richard et al., 2003; Richard, 2004; Richard et al., 2004).

Compost utilization also has been shown to significantly reduce nitrate leaching relative to conventional fertilizers (Maynard, 1993). However, one of the disadvantages of composting is nutrient loss during the composting process, which can occur through leaching, runoff, and volatilization (Christensen, 1983, 1984; Richard and Chadsey, 1994; Eghball et al., 1997; Tiquia et al., 2000, 2002; Garrison et al., 2001). Pare et al. (1997) found that compost windrows with geotextile covers contributed to a reduction of 79.6 percent and 63.1 percent of the compost leachate volume for the spring and summer composting periods, respectively. This leachate volume reduction resulted in better retention of mineral elements in the compost and less risk to groundwater resources.

VFS buffers are bands of vegetation located downslope of cropland or other potential pollutant source areas. The purpose of these strips is to provide erosion control and to filter nutrients, pesticides, sediment, and other pollutants from agricultural runoff by reducing the sediment carrier and through interception-adsorption, infiltration, and degradation of pollutants dissolved in water. VFS buffers have been suggested as one of many BMPs to reduce or prevent non-point source pollution (Magette et al., 1989; Patty et al., 1997).

The effectiveness of VFS buffers in controlling pollutants from cropland has been assessed by many researchers (Dillaha et al., 1985; Mickelson and Baker, 1993; Lee, 2000). These researchers found that VFS buffers have potential for markedly improving the quality of incoming runoff. However, the effectiveness of VFS buffers depends on many factors such as structure and species of the vegetation, soil type, soil texture, type of contaminant, slope of the runoff area, activities on the runoff area (i.e. tillage), and field condition (Dillaha, 1989; Arora et al., 1996; Schmitt et al., 1999; Lee, 2000).

Several studies have documented the effectiveness of VFS buffers with respect to manure management. Lim et al. (1998) studied the effects of VFS buffer length on concentration and transport of N, P, sediment, and fecal coliform in runoff plots treated with cattle manure. The results of the study showed that VFS buffers significantly reduced concentration and mass transport of incoming P, sediment, and fecal coliform. A study conducted by Edwards et al. (1997) assessed the impact of VFS buffer length (0-12 m) on concentration and mass losses of metals (copper, iron, potassium, and zinc) in runoff from fescue grass treated with poultry litter. They reported an effective decrease in metal concentration in outflow.

Windrow Composting Site Runoff Hydrologic Modeling

Computer hydrologic models have been used for over 30 years to simulate sediment and nutrient transport in surface runoff through VFS buffers (Tollner et al., 1976; Delgado et al., 1992; Munoz-Carpena et al., 1993, 1999; Srivastava et al., 1998; Zegre, 2003; Williams et al., 2006). Abu-Zreig (2001) and Abu-Zreig et al. (2001, 2004) extensively evaluated the Vegetative Filter Strip Model (VFSMOD) regarding the relationship of sediment deposition and VFS buffer length. Zhang et al. (2001) used VFSMOD to simulate fecal pathogen transport in VFS buffers and Dosskey et al. (2006) used VFSMOD to develop an approach for using soil surveys to identify suitable VFS buffer sites for water quality improvement. Bhuyan et al. (2003) evaluated the NRCS Curve Number (CN) method used in the Agricultural Non-Point Source Pollution (AGNPS) model to improve soil antecedent moisture condition simulations. Lyon et al. (2004) developed and tested a distributed approach for applying the NRCS-CN equation to watersheds where variable source area hydrology is a dominant process. Jha et al.

(2006) used the Soil and Water Assessment Tool (SWAT) hydrologic model to simulate water quality conditions of the Raccoon River watershed in central Iowa.

Although hydrologic models are extensively used to simulate a variety of surface runoff scenarios, few reports exist regarding the application of these models for predicting runoff losses from windrow composting sites. Governo (2001) reported on a spreadsheet-based computer program to assist in the design phase of windrow composting facilities, but did not include a hydrologic modeling component. Tollner and Das (2004) evaluated hydrologic models that included the NRCS-CN method for predicting runoff from a yard waste windrow composting site. Although this research effort described a hydrologic modeling approach for windrow composting sites, it does not include a runoff modeling function for VFS buffers. Wilson, et al. (2004) collected runoff volume data from a field windrow composting site and a laboratory compost windrow cross-section model. They determined that approximately 68% of natural and simulated rainfall amounts ran off of saturated compost windrows in both field and laboratory experiments, respectively. Wilson et al. (2004) also indicated that one barrier to modeling the hydrology of windrow composting sites is a lack of basic information regarding rainfall-runoff relationships for compost.

Wulf and Lorimor (2005) developed a process-based livestock feedlot runoff model that uses the NRCS-CN method, soil hydraulic conductivity, and weather data to simulate surface runoff through a VFS buffer. This feedlot hydrologic modeling program was modified to simulate runoff volume from a windrow composting site with VFS buffers, and was used for initial model evaluation in this dissertation research project.

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CHAPTER 3: GRAZING AND VEGETATIVE FILTER STRIP BUFFER EFFECTS ON SEDIMENT AND NUTRIENT LOSSES WITH RUNOFF

A paper to be submitted to *Transactions of the ASABE*

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Abstract

This research quantifies the effects of grazing management practices and VFS buffers on losses of runoff (RO) with total solids (TS), nitrate-nitrogen (NO_3-N), ortho-phosphorus (PO_4-P), and total-phosphorus (TP) during natural rainfall events. Runoff data were collected from 12 events during 2001-2003 at an Iowa State University research farm in central Iowa, USA. Three grazing management practices (5.1-cm [2-in] continuous grazing [con], 5.1-cm [2-in] rotational grazing [rot], and no grazing [ng] control) and three VFS buffers (paddock area:buffer area ratios of 5:1, 10:1, and no buffer [NB] control) comprised nine treatment combinations. The nine treatments were replicated in three 2.75 ha (6.8 ac) plot areas for a total of 27 runoff collection units distributed in a randomized complete block design. The plot areas were on uneven terrain with up to 15 percent slopes and consisted of approximately 100 percent smooth brome (*Bromus inermis* Leyss.). Average paddock and VFS buffer plant tiller densities were approximately 62M and 93M tillers/ha, respectively. Results from 2001 and 2002 show no significant differences ($p < 0.10$) in average losses of RO, TS, NO_3-N, PO_4-P, and TP among the nine treatment combinations. The 2003 results also show no significant differences ($p < 0.10$) in losses of RO, TS, PO_4-P, and TP. However, the 2003 results indicate significantly higher ($p < 0.01$) losses of NO_3-N from "10:1ng" treatments compared to all other treatment combinations and reflect a possible tendency towards elevated losses in some "ng" treatments from "con" treatments in 2001 and 2002. Runoff analysis results indicate grazing management practices did not significantly affect runoff losses ($p < 0.10$). These results and other research findings suggest the relatively higher

2003 event precipitation, antecedent moisture, concentrated surface flow conditions, dense cool-season smooth brome, and forage nutrient cycling processes may have contributed to the potential shift of elevated losses to the non-grazed "ng" treatments. Results also suggest warm-season grasses like switchgrass (*Panicum virgatum* L.) could be incorporated into certain paddock areas in a rotational grazing management program to improve grazing efficiency and reduce RO and contaminant losses.

Introduction

Livestock grazing significantly affects the soil-water environment (Schepers and Francis, 1982; Owens et al., 1989; Nelson et al., 1996; Krzic et al., 2006). Grazed pastures can be key contributors of phosphorus (P) to surface waters (Downing et al., 2000), and have higher P losses than non-grazed pastures (Gillingham and Thorrold, 2000). Addiscott et al. (2000) showed that significant P losses could occur from cultivated fields via subsurface drains. Nitrogen (N) losses from agricultural/grazing fields to surface and subsurface waters also have been documented (Madramootoo et al., 1992; Sauer et al., 2000; Stout et al., 2000). Various studies have indicated that N and P losses from continuous grazing pastures are generally higher than rotational grazing and non-grazed pastures (Ritter, 1988; Mathews et al., 1994).

Although livestock grazing activities can adversely impact the complex soil-water environment, Sharpley and Syers (1976) determined that P transport due to grazing animals was significantly less than P losses from fertilizer addition. Nash et al. (2000) found that cattle grazing did not result in large stores of available P compared to P fertilization. Mathews et al. (1994) also found the grazing method of well-managed pastures may have little effect on short-term soil nutrient distribution, especially when grazing occurs during months when temperatures are high. While grazing management practices can have variable effects on runoff, erosion, and nutrient losses from pasture systems, vegetative characteristics of different forage species also can influence the surface hydrology of these landscapes. Self-Davis et al. (2003) researched various forage plant species and cover effects from small vegetated plots and determined that tall fescue (*Festuca arundinacea* Schreber.) significantly reduced runoff and increased infiltration.

Several researchers also have shown the inclusion of warm-season grass types into a rotational grazing sequence cannot only improve vegetation quality and grazing efficiency (Mitchell et al., 1998; Moore et al., 2004; Roberts and Kallenbach, 2006), but may reduce runoff, sediment, and nutrient losses in areas with slopes less than 4 percent (Broadmeadow and Nisbet, 2004).

Vegetative filter strip (VFS) buffers are bands of vegetation located downslope of cropland, livestock grazing areas, and other potential sources of surface runoff and contaminants (Dillaha et al., 1989). These VFS buffers provide erosion control and filter nutrients, pesticides, sediment, and other pollutants from agricultural runoff by reducing the sediment carrier and through interception-adsorption, infiltration, and degradation of pollutants dissolved in water. Various researchers have reported on the effectiveness of VFS buffers in treating agricultural runoff (Snyder et al., 1998; Smith et al., 2000; Bharati et al., 2002; Gharabaghi et al., 2001; Koelsch et al., 2006). VFS buffers also have been suggested as a best management practice (BMP) for removing water pollutants from surface runoff (Dillaha et al., 1989; Mickelson and Baker, 1993; Gilley et al., 2000). A VFS buffer study by Patty et al. (1997) showed a reduction of 47-100 percent and 22-89 percent of NO_3-N and total P, respectively, in runoff. However, Dosskey et al. (2002) assessed the effects of concentrated flow through vegetation and determined this can significantly reduce the efficacy of VFS buffers. Several researchers also have reported that due to the stiff stems and extensive root systems of warm-season grass species, they provide more effective VFS buffer vegetation than some cool-season grasses for reducing sediment, and nutrient losses with runoff (Schultz et al., 1997; Lee et al., 1998; Broadmeadow and Nisbet, 2004).

Smooth brome is a strongly rhizomatous, sod-forming perennial grass that was introduced from Eurasia in 1884 (USGS, 2006) and was reported to be the most agronomically important grass species (Hitchcock, 1950). This aggressive cool-season grass is resistant to temperature extremes and drought due to its highly developed root system and grows best on deep, well-drained silt or clay loam soils (Roberts and Kallenbach, 2006). Now considered to be naturalized over most of North America, smooth brome has escaped throughout its range and is often considered a highly competitive weed of roadsides, forests, prairies, fields, lawns, and lightly disturbed sites (USGS, 2006). Cool-season grasses, such as smooth brome, tend to lay over in runoff flow and are not considered an appropriate vegetation type for VFS buffers (Schultz et al., 1997).

The literature cited in this manuscript focuses on documenting the effects of livestock grazing and VFS buffers on runoff water quality. However, grazing and VFS buffer effects vary with different field conditions that include vegetation species, soil type, soil texture, type of contaminant, slope of the runoff area, paddock:VFS buffer area ratio, and activities on the runoff area. Consequently, this research quantifies the effects of various grazing management practices and VFS buffer treatments on losses of sediment and nutrients in surface runoff. Critical consideration also was given to paddock and VFS buffer area vegetation type, density, and slope conditions.

Materials and Methods

This study was conducted during 2001-2003 at Iowa State University's Rhodes Research and Demonstration Farm in southwest Marshall County, central Iowa, USA (41° 53.615' N, 93° 12.073' W). The study site total area was 8.25 ha (20.4 ac) comprised of three plots, each approximately 2.75 ha (6.8 ac). Each plot was selected on uneven terrain with slopes up to 15 percent in a smooth brome (*Bromus inermis* Leyss.) pasture at the research site. Vegetation species in both paddocks and VFS buffer areas were approximately 100 percent grasses and a trace of mixed broadleaf species. The average grass tiller populations for the paddocks and VFS buffers were estimated to be 62M and 93M tillers/ha, respectively. Percent of tiller species and population was determined using a method from Arora et al. (2003). Each plot was subdivided into five 0.4 ha (1 ac) paddocks and fenced. The major soil association at the research site is the Downs-Gara association with silty and loamy soils formed on upland loess and glacial till. The dominant soil at the research site is Downs silt loam, a fine-silty, mixed, mesic Mollic Hapludalfs (Oelmann, 1981). After initial soil sampling in the spring of 2001, P was applied to the three plot areas within the recommended optimum range of 11-15 ppm P_2O_5. Sandbags were placed around the perimeter of the plot areas and between each paddock to prevent cross-contamination between adjacent paddocks from runoff by rainfall events.

The use of grazing management treatments (continuous grazing to a residual sward height of 5.1 cm (2 in), rotational grazing to a residual sward height of 5.1 cm (2 in), and a non-grazed control) were included to evaluate the effects of grazing practices on water quality. Grazing was initiated on May 29, 2001, with three mature cows (average weights = 657, 613, and 625 kg) in each grazed paddock. In the continuous grazing system, cattle were removed from the paddocks after the sward height decreased to 5.1 cm (2 in). Paddocks were allowed a rest period of 7-10 days to limit re-growth and simulate continuous grazing. Cattle were removed from the paddocks for 35 days after sward height decreased to 5.1 cm (2 in) for the rotational grazing system. Total grazing days for the continuous and rotational grazing systems for 2001, 2002, and 2003 were 491 and 378 cow-days/ha, 400 and 316 cow-days/ha, and 396 and 316 cow-days/ha, respectively.

The role of VFS buffers on losses of runoff (RO), total solids (TS), nitrate-nitrogen (NO_3-N), ortho-phosphorus (PO_4-P), and total-phosphorus (TP) was evaluated by using paddock area:VFS buffer area ratios of 5:1, 10:1, and no VFS buffers (control) for all grazing management practice/VFS buffer treatments. The term "area ratio" represents the ratio of paddock land area draining into a VFS buffer to the area of the VFS buffer. The site included nine grazing practice/VFS buffer treatment combinations, replicated in three 2.75 ha (6.8 ac) plot areas for a total of 27-2.28 m x 22.8 m (7.5 ft x 75 ft) runoff collection units in a randomized complete block design. All of the plot runoff units within paddocks were hydrologically isolated by an 8-cm high barrier that included 15-cm wide sheet metal borders, driven approximately 7 cm into the ground. A tipping-bucket flow meter system (Hansen and Goyal, 2001) was used to measure and collect runoff water from each runoff unit after a rainfall event. A perforated four-inch diameter polyvinyl chloride (PVC) pipe collector was used at the downslope end of each paddock to direct runoff water to the tipping-bucket system through 6 m to 9 m long PVC flow pipes. The runoff samples were collected in 19-L plastic tanks through a plastic tube connected to an orifice in the 90° elbow at the end of the flow pipe for each runoff unit.

Data loggers (Onset Computers Inc., Massachusetts, USA) connected to magnetic switches were used to measure tips for the tipping-bucket units. All plots and tipping-bucket units were checked at least weekly and runoff samples were collected after rainfall events of 25 mm (1.0 in) depth or greater. Samples were refrigerated until analysis at the Department of Agricultural and Biosystems Engineering Water Quality Laboratory, National Swine Research and Information Center, Iowa State University, Ames, Iowa.

TS concentrations (g/kg) in runoff were measured using a gravimetric oven-drying method (Standard Methods, 1998). NO_3-N concentrations (mg/L) were analyzed by the automated flow injection cadmium reduction method using a Lachat Quickchem 2000 Automated Ion Analyzer system and Standard Methods (1998). PO_4-P concentrations (mg/L) were analyzed by the automated flow injection ascorbic acid method using a Lachat Quickchem 2000 Automated Ion Analyzer system. TP concentrations (mg/L) from filtered runoff samples also were determined by using the ascorbic acid method (Hach Company, 2002). All TS and nutrient (NO_3-N, PO_4-P, and TP) concentrations were converted to total loss units of g and mg, respectively. Volumes of runoff were determined from the tipping-bucket units and were converted to equivalent depth in millimeters across each grazing management practice/VFS buffer runoff treatment combination. The significance between treatments was determined by using SAS software (SAS Institute, 2004). The GLM Procedure and LSMEANS Test were used to analyze differences among the grazing management practice and VFS buffer treatment means.

Results and Discussion

Runoff Analysis and VFS Buffer Performance

There were a total of 12 rainfall events used for analysis during 2001, 2002, and 2003 project seasons at the ISU Rhodes research site. These event dates and rainfall depths for each project year are shown in Table 1. This manuscript discusses average concentration and total loss data values of the individual events for each of the three project years: 2001 (total event rainfall = 332 mm), 2002 (total event rainfall = 129 mm), and 2003 (total event rainfall = 397 mm).

Average losses of RO (mm) and TS (g) for 2001, 2002, and 2003 are shown in Figures 1, 3, and 5, respectively. Likewise, average losses of NO_3-N (mg), PO_4-P (mg), and TP (mg) are shown in Figures 2, 4, and 6, respectively. These losses values are calculated across nine VFS buffer/grazing management practice treatment combinations that are shown in Table 2. Results from 2001 (Figures 1 and 2) and 2002 (Figures 3 and 4) show no significant differences ($p < 0.10$) in average losses of RO, TS, NO_3-N, PO_4-P, and TP among the nine treatment combinations. Relatively lower runoff depths, and sediment and variable nutrient loss values from 2001 (total event rainfall = 332 mm) may be partly attributed to runoff collection pipe leakage that was discovered and repaired during the 2001 project season. The 2003 results (Figures 5 and 6) also show no significant differences ($p < 0.10$) in average losses of RO, TS, PO_4-P, and TP, but indicate significantly higher ($p < 0.01$) average losses of NO_3-N from the "10:1ng" treatment combination (Figure 6).

Least square means (LSMEANS) values of RO, TS, NO_3-N, PO_4-P, and TP average losses for 2001, 2002, and 2003 are shown in Tables 3, 4, and 5, respectively. These LSMEANS values are for the six individual grazing management practice (con, rot, and ng) and VFS buffer (5:1, 10:1, NB) treatments. LSMEANS for 2001 and 2002 (Tables 3 and 4, respectively), while not significant, indicate a possible tendency towards higher loss values in the "con" treatments, which is similar to findings from other studies (Ritter, 1988; Mathews et al., 1994). However, the LSMEANS from 2003 (Table 5) reflect a possible tendency towards elevated loss values in the "ng" treatments, and the "NB" treatment values were relatively higher than the 5:1 and 10:1 VFS buffer treatments for all three years (Tables 3, 4, and 5).

Although the 2001 and 2002 LSMEANS values (Tables 3 and 4) indicating the 5:1 and 10:1 VFS buffer treatments were not significantly different ($p < 0.10$) in reducing losses are similar to other findings (Arora et al., 2003), the 2003 results (Table 5), showing relatively higher runoff depth and significantly higher ($p < 0.01$) NO_3-N losses from "ng" (no grazing) pastures, and 10:1 VFS buffer treatments, contradict results from other studies (Ritter, 1988; Mathews et al., 1994; Mwendera et al., 1997; Sauer et al., 2000). However, researchers have reported that VFS buffers are most effective when flow is shallow and slow (Barling and Moore, 1994) and that concentrated flow through VFS buffers can be substantial and may greatly limit filtering effectiveness (Dosskey et al., 2002). Cool-season grass species like smooth brome found at the Rhodes research site also are not as effective in reducing RO, TS, and contaminants as some warm-season grass types (Schultz et al., 1997; Lee et al., 1998; Broadmeadow and Nisbet, 2004) and may have contributed the potentially higher runoff losses of 2003.

Average concentrations of TS (g/kg) for 2001, 2002, and 2003 are shown in Figures 7, 9, and 11, respectively and are not significantly different among treatment combinations ($p < 0.10$). Average concentrations of NO_3-N (mg/L), PO_4-P (mg/L), and TP (mg/L) are shown in Figures 8, 10, and 12, respectively and also are not significantly different among treatment combinations ($p < 0.10$). However, the relatively lower concentration value of NO_3-N in the "10:1ng" treatment combination (Figure 12) reflects the elevated runoff volume for that treatment combination (Figure 5 and 11) and a subsequent significantly higher ($p < 0.01$) NO_3-N average loss value (Figure 6) for the 2003 project season.

Vegetation and Runoff Flow Characteristics

The Rhodes research site is an excellent location for smooth brome establishment with its silt loam soils and well-drained steep terrain. Brueland et al. (2003) estimated the maximum smooth brome plant density of their Rhodes site research plots to be approximately 50M tillers/ha in 1996. Arora et al. (2003) also determined the average tiller population was approximately 9M tillers/ha for VFS buffers at another central Iowa research site. For this study, the paddock and VFS buffer plot areas were estimated in 2003 to be 62M and 93M tillers/ha, respectively. Smooth brome can become heavily established with adequate rainfall during spring and early summer, and depending on soil moisture availability, may re-grow in September and October (USGS, 2006). The 30-year average annual precipitation at the Rhodes site was 891 mm (35 in), with the majority of rainfall (54 percent) occurring from May-August (Haan et al., 2007).

Precipitation was slightly above average during 2001 (932 mm [37 in]) and 2003 (965 mm [38 in]), and slightly below average during 2002 (716 mm [28 in]; NOAA 2001, 2002, 2003).

Prior to 2001, the Rhodes site had been managed as a single unit for beef cattle grazing and hay harvest for over 20 years (Haan et al., 2007). Since 5-10 years may be required to modify soil conditions in a new grass management system (Richard Schultz, per comm.), this may have contributed to the runoff losses variability in this study. Dosskey et al. (2007) also found that the most change in VFS buffers occurred within three growing seasons after establishment, and infiltration characteristics accounted for most of that change. These changes, coupled with the greater frequency of rainfall events (five) and antecedent moisture conditions, also may have enhanced the hydrologic dynamics of the 2003 project season.

Research comparing smooth brome to warm-season species, like switchgrass and big bluestem, shows that warm-season grasses are more effective VFS buffer vegetation for reducing RO, TS, and nutrient losses. Lee et al. (1998) found that switchgrass under simulated rainfall conditions removed significantly more NO_3-N, PO_4-P, and TP than cool-season VFS buffers that included smooth brome. Lee et al. (1998) also reported that warm-season switchgrass VFS buffers were more effective in removing TS compared to nutrients, and the VFS buffers were least effective in removing NO_3-N. Schultz et al. (1997) reported that switchgrass is preferred for VFS buffers due to its dense, stiff stems that slow runoff and cool-season grasses such as smooth brome are not appropriate since they do not tend to remain upright under the flow of water. Broadmeadow and Nisbet (2004) also indicated that VFS buffer efficiency was likely to be greatly reduced on slopes above 4 percent due to the vegetation becoming flattened by surface runoff during high rainfall.

Although warm-season grasses have been extensively documented as effective VFS buffer vegetation, these grass species also have been suggested for incorporation into livestock pasture areas for a rotational grazing management sequence (Mitchell et al., 1998; Moore et al., 2004; Roberts and Kallenbach, 2006). However, most of the warm-season native grass mixtures are recommended for slopes of 0-5 percent (SCS, 1979).

The Rhodes site has a maximum slope of 15 percent, and smooth brome is one of the few suitable grasses recommended for slopes greater than 10 percent (SCS, 1979) due largely to the "sod" growth characteristic of smooth brome versus the "bunch grass" growth pattern of switchgrass (Richard Schultz, per comm.). To better understand the effect of smooth brome on surface runoff under the steep terrain conditions at the Rhodes site, a quantitative approach may be helpful. To determine surface runoff flow velocity under different vegetation and slope conditions, the Manning equation is widely used because of its simplicity and accuracy (Fangmeier et al., 2006). Assuming steady, uniform flow, the Manning equation (USDOT, 1986) can be expressed in the following Equation 1 as:

$$v = R^{0.67} S^{0.50}/n \qquad (1)$$

For Equation 1, v = mean velocity (m/s), n = Manning coefficient of channel roughness (dimensionless), R = hydraulic radius (m), and S = slope of the energy grade line (dimensionless). For most channel lining materials such as soil and concrete, the Manning "n" value does not vary significantly as the depth of flow varies, and is normally assumed to be constant. However, for vegetative channels and flow paths, the Manning "n" value varies greatly with depth of flow (USDOT, 1986). Ree (1949) studied the hydraulic characteristics of vegetation and determined that the Manning "n" value varied from approximately 0.40 at 30 percent (initial) submergence to 0.03 at 100 percent (complete) submergence for a Bermuda grass channel on a 5 percent bed slope. To simplify application of the Manning n values to initial and complete vegetation submergence conditions, NRCS determined a Manning "n" value range of 0.50-0.02, respectively, for all channel vegetation types (IDOT, 2006).

Since the smooth brome paddock and VFS buffer grass vegetation at the Rhodes site is in the same Retardance Class (B) as Bermuda grass (SCS, 1979), the NRCS Manning "n" value range of 0.50-0.02 may be a reasonable estimate. Substituting the Manning "n" values of 0.50 and 0.02 into Equation 1 ($R^{0.67} = 0.34$; $S^{0.50} = 0.40$), the runoff velocities (v) equal 0.27 m/s (0.89 ft/s) and 6.8 m/s (22.31 ft/s) for initial and complete vegetation submergence, respectively. The upper 6.8 m/s value is a 25-fold increase in runoff velocity due to smooth brome vegetation submergence and flattening. The high flow velocity value also exceeds by almost five-fold the NRCS Permissible

Velocity value of 1.5 m/s recommended for smooth brome established on slopes greater than 10 percent (SCS, 1979). Lee et al. (1998) reported that VFS buffers were more effective in removing TS from surface runoff than in removing nutrients, and the removal of NO_3-N is mainly dependent on infiltration. Since higher RO velocities estimated by the Manning equation are inversely related to runoff residence time and, subsequently, nutrient removal in the VFS buffer area, the results appear to be consistent with the 2003 Rhodes site runoff analysis results. These results also may have contributed to the significantly higher levels ($p < 0.01$) of NO_3-N losses from the "10:1ng" treatment combination plots, and a possible tendency towards elevated losses from the "con" grazing treatments in 2001 and 2002 to the "ng" control treatment plots in 2003. Haan et al. (2007) also reported that grazing stimulates new shoot and root growth, and non-grazed pastures can gradually lose their capacity to sequester sediment and nutrients.

Summary and Conclusions

This research quantifies the effects of grazing management practices and VFS buffers on losses of runoff (RO) with total solids (TS), nitrate-nitrogen (NO_3-N), ortho-phosphorus (PO_4-P), and total-phosphorus (TP) during natural rainfall events. Runoff data were collected from 12 events during 2001-2003 at the Iowa State University Rhodes Research and Demonstration Farm located in central Iowa, USA.

Results from 2001 and 2002 show no significant differences ($p < 0.10$) in average losses of RO, TS, NO_3-N, PO_4-P, and TP among the nine treatments. The 2003 results also show no significant differences ($p < 0.10$) in losses of RO, TS, PO_4-P, and TP. However, the 2003 results indicate significantly higher ($p < 0.01$) losses of NO_3-N from "10:1ng" treatments compared to all other treatment combinations and, while not significant, may indicate a tendency towards elevated losses to some "ng" treatments from the "con" treatments in 2001 and 2002. Although there were no significant differences ($p < 0.10$) among treatment combinations for the 2001, 2002, and 2003 average TS and nutrient concentration results, the relatively higher runoff volume for the "10:1ng" treatment combination complements the significantly higher NO_3-N losses with runoff.

Overall, the runoff analysis results indicate grazing management practice did not significantly affect runoff. These results also suggest the relatively higher 2003 event precipitation depth, antecedent moisture conditions, and the dense cool-season smooth brome may have contributed to the potential shift of elevated losses to the non-grazed "ng" control treatments. Concentrated flow conditions through the paddocks and VFS buffers also may have contributed to elevated runoff and NO_3-N losses (Dosskey et al., 2002) since the Rhodes research site is located in the Southern Iowa Drift Plain Landform, a generally high-relief landscape that is characterized by an extensive drainage network of deeply-incised rills, ravines, and stream channels (Prior, 1991). Research comparing smooth brome to warm-season species, like switchgrass and big bluestem, shows that warm-season types are more effective VFS buffer vegetation for reducing RO, TS, and nutrient losses. However, the Rhodes site includes slopes up to 15 percent, and the sod-forming smooth brome is recommended for areas with slopes greater than 10 percent (SCS, 1979).

Although warm-season grasses could be incorporated into a rotational grazing management program to improve grazing efficiency and reduce RO and contaminant losses, Vinton and Goergen (2006) suggested that smooth brome may have a competitive advantage over warm-season switchgrass on higher-N soils. Consequently, the increased N deposition associated with livestock grazing and fertilizer application could result in an even greater smooth brome competitive advantage, requiring special vegetation management strategies such as prescribed burning. By locating the warm-season grass paddocks low in the landscape adjacent to the VFS buffers and smooth brome on the upslope areas, prescribed burning could be effectively applied to the warm-season grass areas to reduce the aggressive smooth brome encroachment. Current research indicates that annually repeated mid- to late spring (May to early June) prescribed burning reduces smooth brome tiller numbers, favoring growth and development of warm-season grass species (USGS, 2006).

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Table 1. Rainfall data (event date, number [E1-E12], and rainfall depth) for 2001, 2002, and 2003 grazing management practice/VFS buffer study at Iowa State University Rhodes Research and Demonstration Farm, central Iowa, USA.

Project Year	2001	2002	2003
Event Date, Number, and Rainfall Depth	7-19-01 E1 76 mm 8-3-01 E2 58 mm 9-7-01 E3 127 mm 10-22-01 E4 71 mm	6-12-02 E5 42 mm 7-10-02 E6 44mm 8-23-02 E7 43mm	5-4-03 E8 52mm 6-26-03 E9 58mm 7-5-03 E10 48mm 9-12-03 E11 108 mm 11-4-03 E12 131mm
Total Rainfall	332 mm	129 mm	397 mm

Table 2. Vegetative filter strip (VFS) buffer ratios (5:1, 10:1, and NB [no buffer]) and grazing management practices (continuous [con], rotational [rot], and no grazing [ng]) treatment combinations for 2001, 2002, and 2003 grazing management practice/VFS buffer study at Iowa State University Rhodes Research and Demonstration Farm, central Iowa, USA.

VFS Buffer Area	Grazing Management Practice		
paddock:VFS buffer	con	rot	ng
5:1	5:1con	5:1rot	5:1ng
10:1	10:1con	10:1rot	10:1ng
NB	NBcon	NBrot	NBng

Table 3. Grazing management practice (con, rot, and ng for continuous, rotational, and no grazing, respectively) and VFS buffer area (5:1 and 10:1 paddock:VFS buffer area ratios, and NB [no buffer] control) treatment least square means (LSMEANS) values for average losses of runoff (RO), total solids (TS), nitrate-nitrogen (NO_3-N), ortho-phosphorus (PO_4-P), and total-phosphorus (TP) for 2001 rainfall events at Iowa State University Rhodes Research and Demonstration Farm, central Iowa, USA (total events rainfall = 332 mm).

	Grazing Mgt Practice			VFS Buffer Area		
Quantity (units)	con	rot	ng	5:1	10:1	NB
RO (mm)	4.40	4.13	2.05	2.46	4.11	4.02
TS (g)	114	95.0	48.2	60.4	83.9	113
NO_3-N (mg)	228	202	25.4	55.6	205	195
PO_4-P (mg)	159	127	50.3	108	121	107
TP (mg)	249	198	105	160	193	199

Table 4. Grazing management practice (con, rot, and ng for continuous, rotational, and no grazing, respectively) and VFS buffer area (5:1 and 10:1 paddock:VFS buffer area ratios, and NB [no buffer] control) treatment least square means (LSMEANS) values for average losses of runoff (RO), total solids (TS), nitrate-nitrogen (NO_3-N), ortho-phosphorus (PO_4-P), and total-phosphorus (TP) for 2002 rainfall events at Iowa State University Rhodes Research and Demonstration Farm, central Iowa, USA (total events rainfall = 129 mm).

	Grazing Mgt Practice			VFS Buffer Area		
Quantity (units)	con	rot	ng	5:1	10:1	NB
RO (mm)	5.26	5.65	5.33	5.31	2.76	8.17
TS (g)	182	96.2	28.0	78.0	24.4	204
NO_3-N (mg)	115	188	195	148	79.4	271
PO_4-P (mg)	100	208	385	217	147	329
TP (mg)	475	393	781	568	267	814

Table 5. Grazing management practice (con, rot, and ng for continuous, rotational, and no grazing, respectively) and VFS buffer area (5:1 and 10:1 paddock:VFS buffer area ratios, and NB [no buffer] control) treatment least square means (LSMEANS) values for average losses of runoff (RO), total solids (TS), nitrate-nitrogen (NO_3-N), ortho-phosphorus (PO_4-P), and total-phosphorus (TP) for 2003 rainfall events at Iowa State University Rhodes Research and Demonstration Farm, central Iowa, USA (total events rainfall = 397 mm; bolded values are significantly different [$p < 0.01$]).

	Grazing Mgt Practice			VFS Buffer Area		
Quantity (units)	con	rot	ng	5:1	10:1	NB
RO (mm)	5.50	13.73	17.23	4.86	15.55	16.04
TS (g)	45.8	101	200	51.8	140	164
NO_3-N (mg)	94.6	200	**371**	117	**304**	244
PO_4-P (mg)	228	493	209	262	281	387
TP (mg)	251	541	229	288	308	425

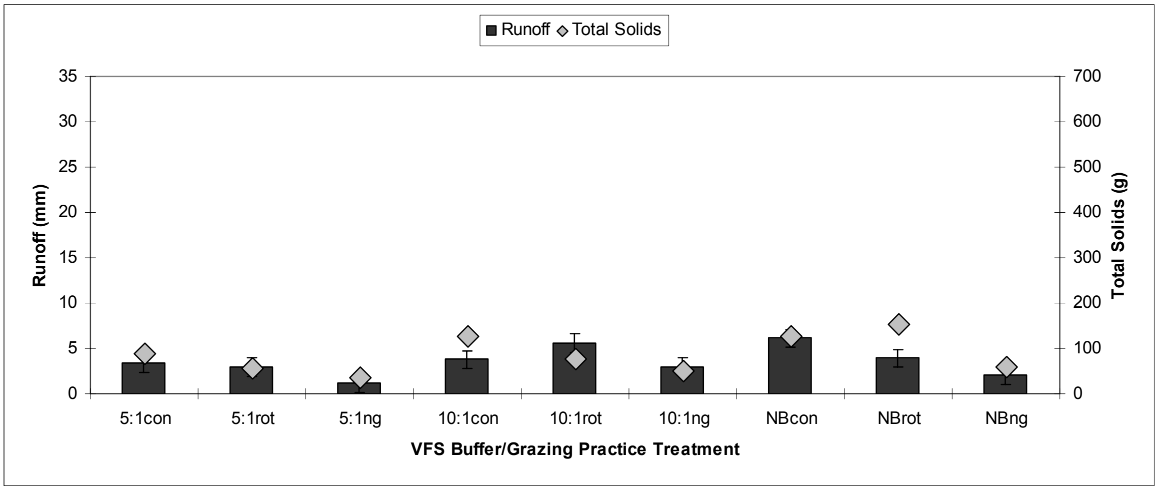

Figure 1. Effects of grazing management practice (con, rot, and ng for continuous, rotational, and no grazing, respectively) and VFS buffer area (5:1 and 10:1 paddock:VFS buffer area ratios, and NB [no buffer] control) treatments on average runoff depth (mm) and total solids losses (g) for 2001 rainfall events at Iowa State University Rhodes Research and Demonstration Farm, central Iowa, USA. There are no significant differences among treatment combinations and error bars represent one standard deviation (total event rainfall = 332 mm).

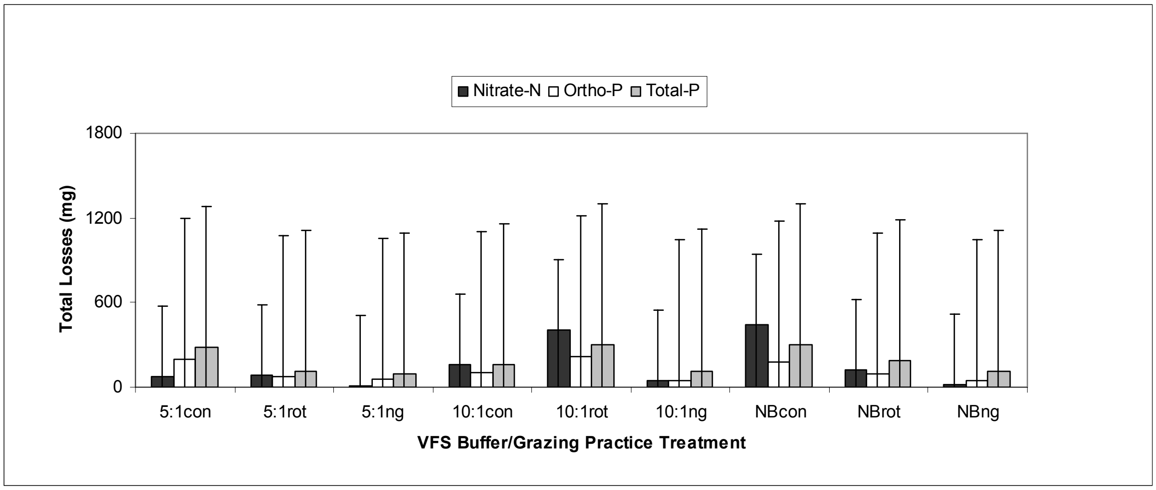

Figure 2. Effects of grazing management practice (con, rot, and ng for continuous, rotational, and no grazing, respectively) and VFS buffer area (5:1 and 10:1 paddock:VFS buffer area ratios, and NB [no buffer] control) treatments on average nitrate-N, ortho-P, and total-P losses (mg) for 2001 rainfall events at Iowa State University Rhodes Research and Demonstration Farm, central Iowa, USA. There are no significant differences among treatment combinations and error bars represent one standard deviation (total event rainfall = 332 mm).

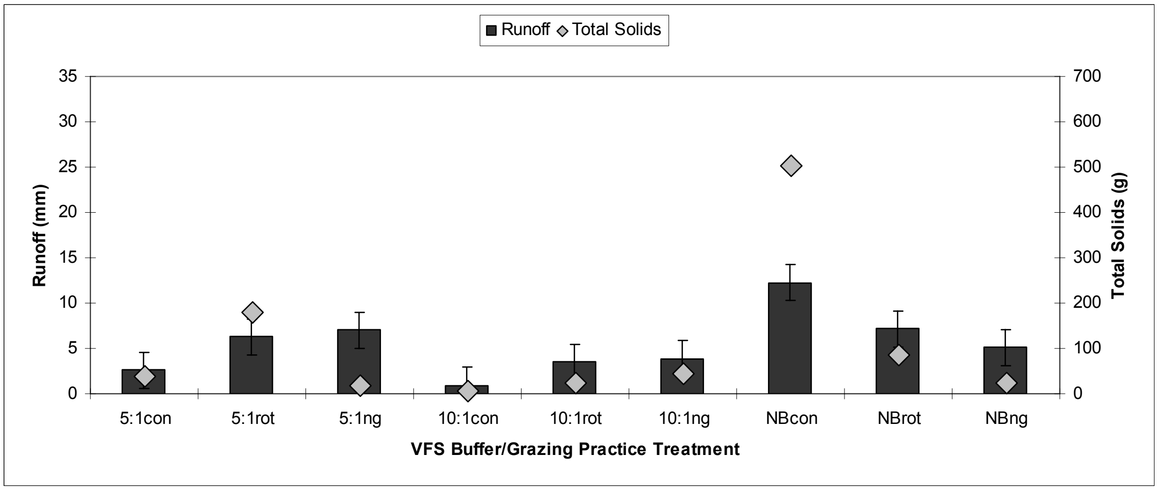

Figure 3. Effects of grazing management practice (con, rot, and ng for continuous, rotational, and no grazing, respectively) and VFS buffer area (5:1 and 10:1 paddock:VFS buffer area ratios, and NB [no buffer] control) treatments on average runoff depth (mm) and total solids losses (g) for 2002 rainfall events at Iowa State University Rhodes Research and Demonstration Farm, central Iowa, USA. There are no significant differences among treatment combinations and error bars represent one standard deviation (total event rainfall = 129 mm).

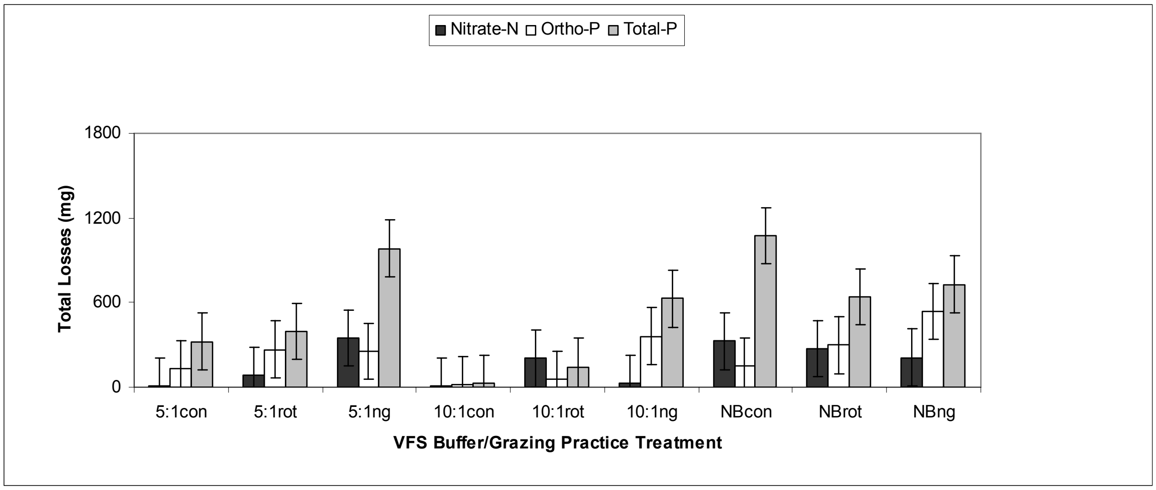

Figure 4. Effects of grazing management practice (con, rot, and ng for continuous, rotational, and no grazing, respectively) and VFS buffer area (5:1 and 10:1 paddock:VFS buffer area ratios, and NB [no buffer] control) treatments on average nitrate-N, ortho-P, and total-P losses (mg) for 2002 rainfall events at Iowa State University Rhodes Research and Demonstration Farm, central Iowa, USA. There are no significant differences among treatment combinations and error bars represent one standard deviation (total event rainfall = 129 mm).

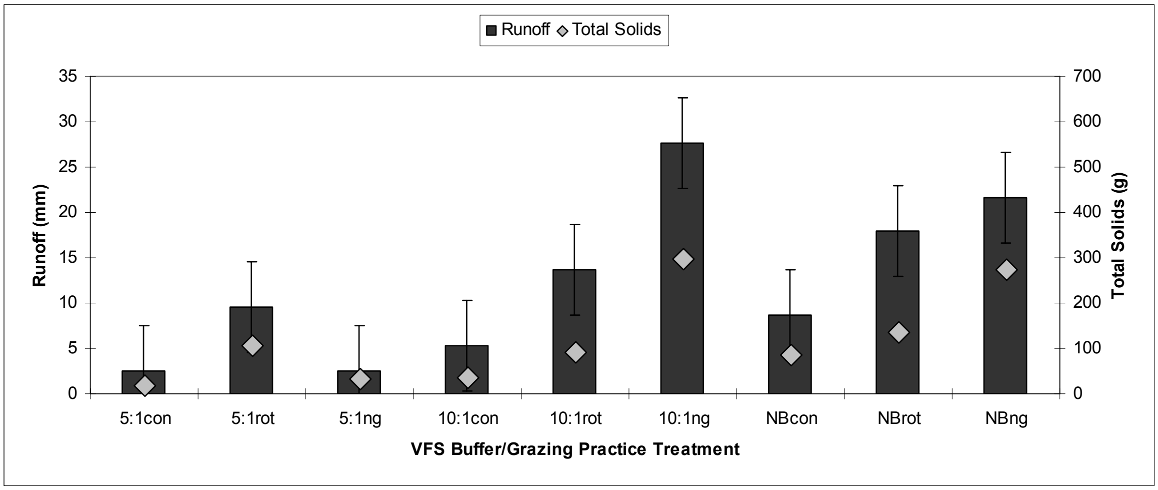

Figure 5. Effects of grazing management practice (con, rot, and ng for continuous, rotational, and no grazing, respectively) and VFS buffer area (5:1 and 10:1 paddock:VFS buffer area ratios, and NB [no buffer] control) treatments on average runoff depth (mm) and total solids losses (g) for 2003 rainfall events at Iowa State University Rhodes Research and Demonstration Farm, central Iowa, USA. There are no significant differences among treatment combinations and error bars represent one standard deviation (total event rainfall = 397 mm).

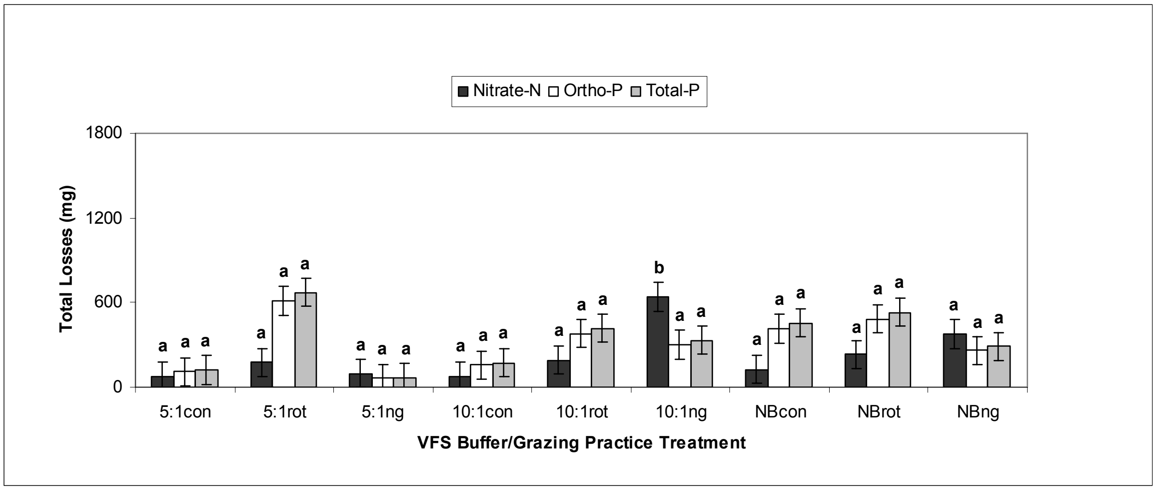

Figure 6. Effects of grazing management practice (con, rot, and ng for continuous, rotational, and no grazing, respectively) and VFS buffer area (5:1 and 10:1 paddock:VFS buffer area ratios, and NB [no buffer] control) treatments on average nitrate-N, ortho-P, and total-P losses (mg) for 2003 rainfall events at Iowa State University Rhodes Research and Demonstration Farm, central Iowa, USA. Significant differences among treatment combinations for each nutrient are indicated by different letters and error bars represent one standard deviation (total event rainfall = 397 mm).

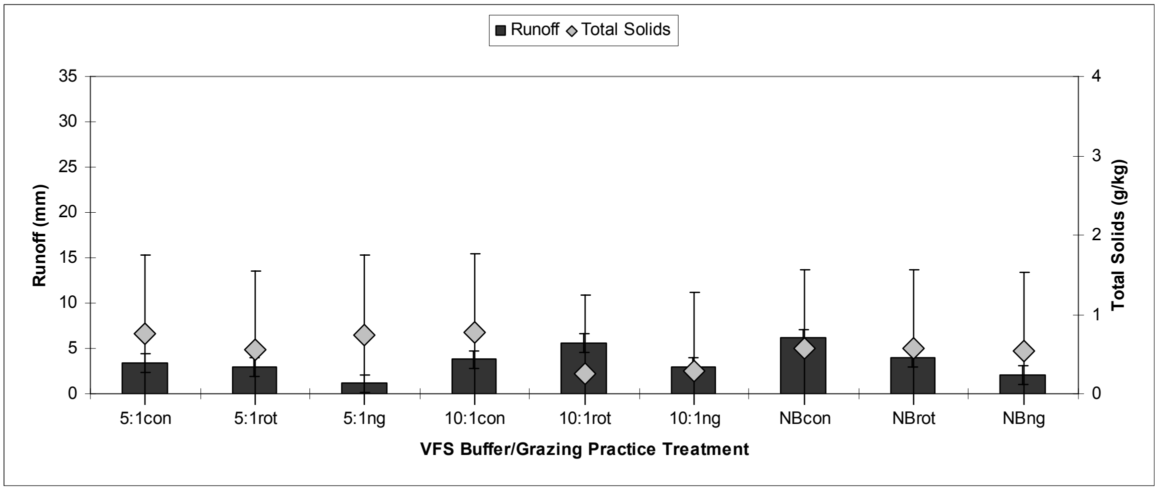

Figure 7. Effects of grazing management practice (con, rot, and ng for continuous, rotational, and no grazing, respectively) and VFS buffer area (5:1 and 10:1 paddock:VFS buffer area ratios, and NB [no buffer] control) treatments on average runoff depth (mm) and total solids concentrations (g/kg) for 2001 rainfall events at Iowa State University Rhodes Research and Demonstration Farm, central Iowa, USA. There are no significant differences among treatment combinations and error bars represent one standard deviation (total event rainfall = 332 mm).

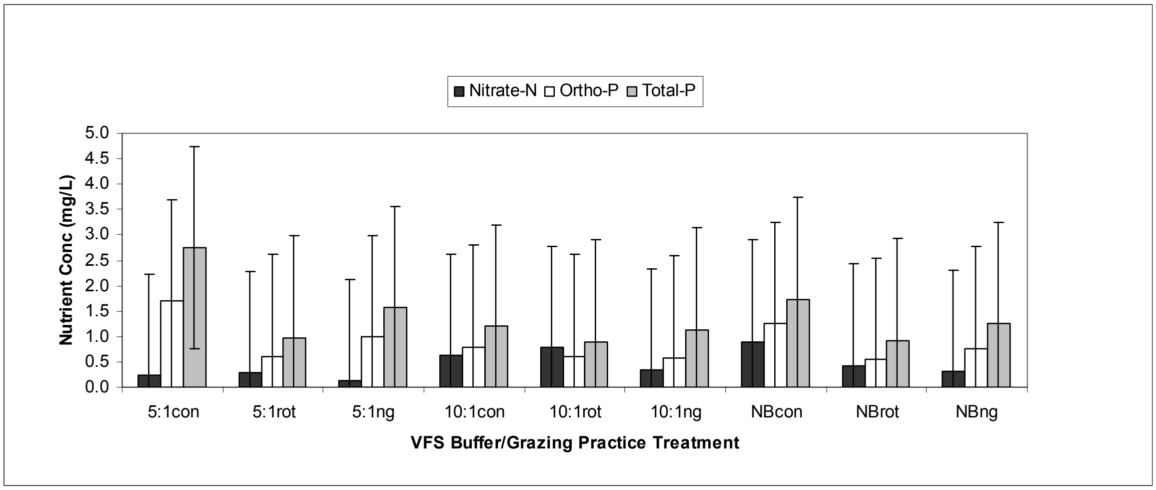

Figure 8. Effects of grazing management practice (con, rot, and ng for continuous, rotational, and no grazing, respectively) and VFS buffer area (5:1 and 10:1 paddock:VFS buffer area ratios, and NB [no buffer] control) treatments on average nitrate-N, ortho-P, and total-P concentrations (mg/L) for 2001 rainfall events at Iowa State University Rhodes Research and Demonstration Farm, central Iowa, USA. There are no significant differences among treatment combinations and error bars represent one standard deviation (total event rainfall = 332 mm).

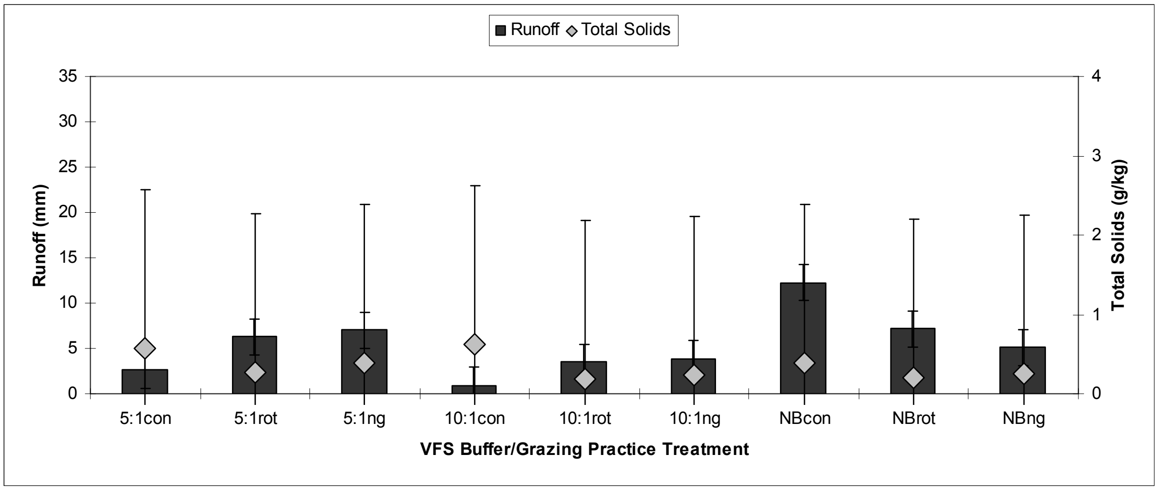

Figure 9. Effects of grazing management practice (con, rot, and ng for continuous, rotational, and no grazing, respectively) and VFS buffer area (5:1 and 10:1 paddock:VFS buffer area ratios, and NB [no buffer] control) treatments on average runoff depth (mm) and total solids concentrations (g/kg) for 2002 rainfall events at Iowa State University Rhodes Research and Demonstration Farm, central Iowa, USA. There are no significant differences among treatment combinations and error bars represent one standard deviation (total event rainfall = 129 mm).

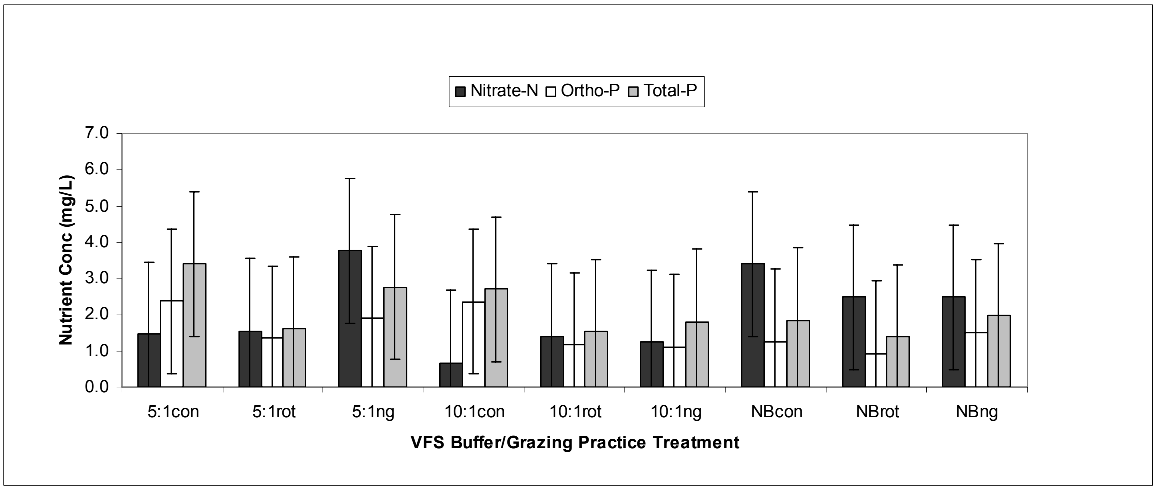

Figure 10. Effects of grazing management practice (con, rot, and ng for continuous, rotational, and no grazing, respectively) and VFS buffer area (5:1 and 10:1 paddock:VFS buffer area ratios, and NB [no buffer] control) treatments on average nitrate-N, ortho-P, and total-P concentrations (mg/L) for 2002 rainfall events at Iowa State University Rhodes Research and Demonstration Farm, central Iowa, USA. There are no significant differences among treatment combinations and error bars represent one standard deviation (total event rainfall = 129 mm).

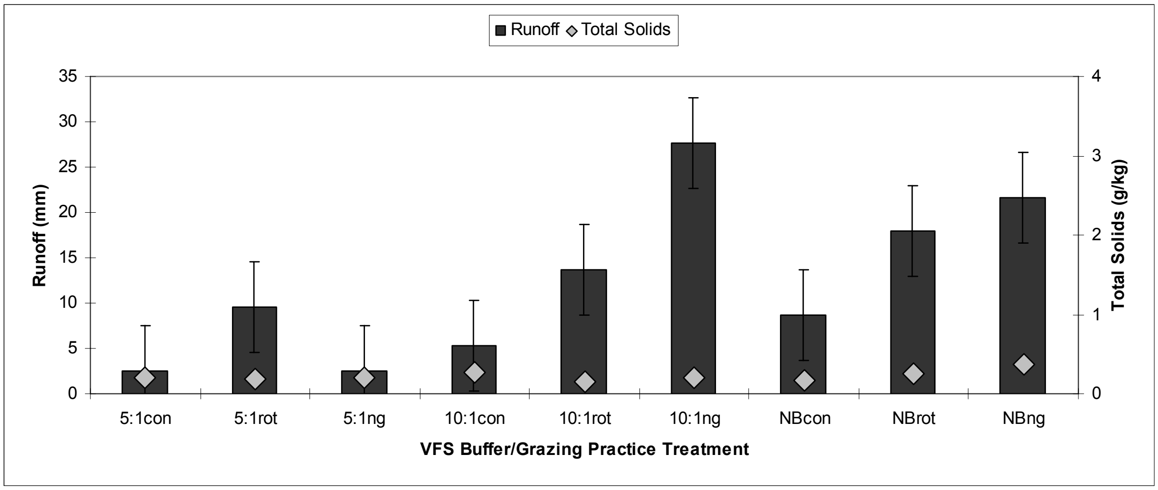

Figure 11. Effects of grazing management practice (con, rot, and ng for continuous, rotational, and no grazing, respectively) and VFS buffer area (5:1 and 10:1 paddock:VFS buffer area ratios, and NB [no buffer] control) treatments on average runoff depth (mm) and total solids concentrations (g/kg) for 2003 rainfall events at Iowa State University Rhodes Research and Demonstration Farm, central Iowa, USA. There are no significant differences among treatment combinations and error bars represent one standard deviation (total event rainfall = 397 mm).

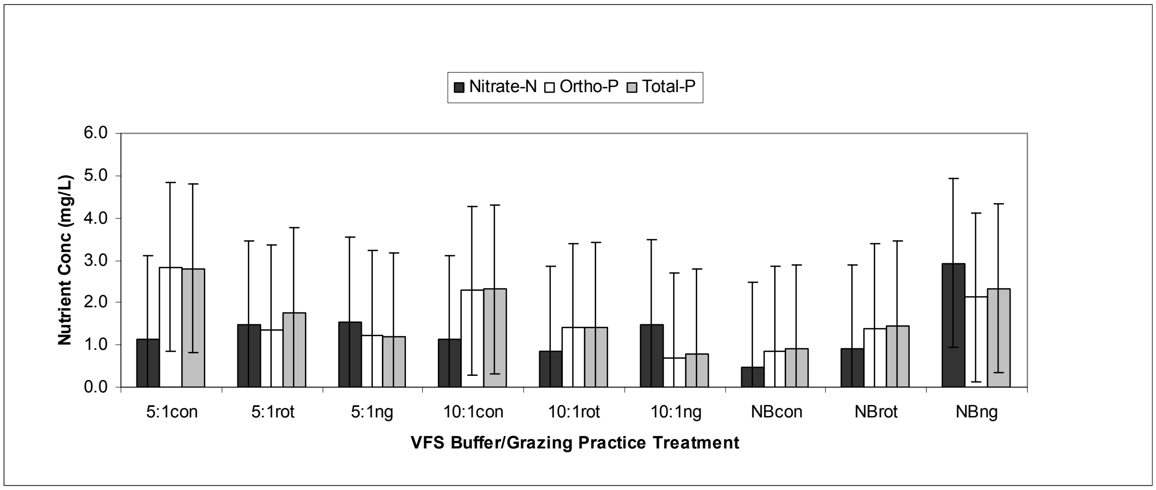

Figure 12. Effects of grazing management practice (con, rot, and ng for continuous, rotational, and no grazing, respectively) and VFS buffer area (5:1 and 10:1 paddock:VFS buffer area ratios, and NB [no buffer] control) treatments on average nitrate-N, ortho-P, and total-P concentrations (mg/L) for 2003 rainfall events at Iowa State University Rhodes Research and Demonstration Farm, central Iowa, USA. There are no significant differences among treatment combinations and error bars represent one standard deviation (total event rainfall = 397 mm).

CHAPTER 4: SEDIMENT AND NUTRIENT LOSSES WITH RUNOFF FROM A WINDROW COMPOSTING SITE WITH VEGETATIVE FILTER STRIP BUFFERS

A paper to be submitted to *Journal of Soil and Water Conservation*

D.F. Webber, S.K. Mickelson, T.L. Richard, and H.K. Ahn

Abstract

This study quantifies the effects of windrow composting practices and vegetative filter strip (VFS) buffers on losses of runoff (RO), runoff percent of rainfall (RO%), total solids (TS), nitrate-nitrogen (NO_3-N), ortho-phosphorus (PO_4-P), and total-phosphorus (TP) during natural rainfall events. Runoff data from six events were collected during June-July (early season) and August-September (late season) 60-day composting periods from 2002-2004 at an Iowa State University research farm near Ames, central Iowa, USA. Runoff treatments were comprised of three compost windrow:VFS buffer area ratios that included 1:1, 1:0.5, and 1:0 (no buffer) control. The 1:1 and 1:0.5 area ratios represented a 6 m x 23 m (20 ft x 75 ft) fly ash composting pad area compared to VFS buffer areas of equal and one-half size, respectively. All treatments had three replications for a total of nine runoff plots distributed in a randomized complete block design. Results from the study indicate significantly higher levels ($p < 0.05$) of RO, RO%, TS, NO_3-N, PO_4-P, and TP from the 1:0 control plots compared to the 1:1 and 1:0.5 plots. Results also show the 1:1 and 1:0.5 VFS buffer treatments were not significantly different ($p < 0.05$). Average runoff loss reductions from the 1:1 and 1:0.5 plots were 98 and 93 percent, respectively, compared to the 1:0 control plots. These results reflect the effectiveness of VFS buffers for reducing runoff and contaminant losses from a windrow composting site. Compost nutrient mass balance analysis results indicate 26-41 percent of PO_4-P was lost from the compost windrows during the 2004 composting periods. However, only 0.1-0.4 percent of PO_4-P was lost to runoff from the 1:0 control plots. We hypothesize the significantly lower PO_4-P losses in runoff may be attributed to potential chemical and physical effects of the fly ash composting pad material.

Introduction

The management and utilization of livestock manures continue to pose hazards to the quality of receiving streams and lakes. In the US, two-thirds of the total beef cattle feeding is practiced in the central and southern Great Plains (Krause, 1991). Handling of manure produced in large feedlots and dairies is a significant environmental problem for water, air, and land pollution. Manure is an excellent source of organic matter and plant nutrients, but even under proper management, conventional manure utilization can have negative impacts. Land application of manure to agricultural fields can elevate runoff concentrations of nutrients such as nitrogen (N), carbon (C), and phosphorus (P) (Westerman et al., 1987; Edwards and Daniel, 1993; Heathwaite et al., 1998). Surface runoff of nutrients from agricultural fields is a major source of water pollution in surface waters in the US (Parry, 1998). One strategy to minimize the adverse effects of livestock manure on the environment is windrow composting.

Windrow composting consists of placing manure and other raw materials in long narrow piles or windrows which are agitated or turned on a regular basis (Rynk et al., 1992). Studies have shown that composted manure is less hazardous to the environment (Eghball and Power, 1999; Vervoort et al., 1998) and much of the mineral N is converted to more stable organic forms (Rynk et al., 1992). Compost also has been shown to significantly reduce P in runoff from road construction sites (Jurries 2003) and nitrate (NO_3-N) leaching relative to conventional fertilizers (Maynard, 1993). However, one of the disadvantages of composting is nutrient loss during the composting process, which can occur through leaching, runoff, and volatilization (Christensen, 1983, 1984; Richard and Chadsey, 1994; Eghball et al., 1997; Tiquia et al., 2000). Mass balance analysis results of a composting site indicated 20-60 percent losses of N, P, and potassium (K) during composting processes (Tiquia et al., 2002), of which the most significant losses were runoff and leachate (Garrison et al., 2001). Seymour and Bourdon (2003) reported concentrations of NO_3-N, ortho-P (PO_4-P), and K were highest in leachate compared to runoff samples from compost windrows under natural rainfall conditions. Wilson et al. (2004) reported that approximately 68 percent of rainfall incident on saturated compost windrows from both natural and simulated rainfall events resulted in runoff.

Vegetative filter strip (VFS) buffers are bands of vegetation located downslope of cropland or other potential pollutant source areas. These buffer strips provide erosion control and filter nutrients, pesticides, sediment, and other pollutants from agricultural runoff by reducing the sediment carrier and through interception-adsorption, infiltration, and degradation of pollutants dissolved in water (Dillaha et al., 1989). VFS buffers also have been suggested as a best management practice (BMP) that has been shown to reduce sediment and nutrient losses in a range of agricultural settings, including crop fields and feedlots (Magette et al., 1989; Patty et al., 1997). The effectiveness of VFS buffers in controlling pollutants from cropland also has been assessed by several researchers (Dillaha et al., 1985; Mickelson and Baker, 1993; Lee, 2000). These researchers found that VFS buffers have potential for significantly improving the water quality of runoff. However, the effectiveness of VFS buffers depends on many factors, such as vegetation species, soil type, soil texture, type of contaminant, slope of the runoff area, activities on the runoff area (i.e. tillage), and field condition (Dillaha et al., 1989; Arora et al., 1996; Schmitt et al., 1999; Lee, 2000; Abu-Zreig et al., 2003; Goel et al., 2004; Petersen and Vondracek, 2006).

Proper windrow composting site selection is critical to many aspects of a composting operation, including materials transport, road access, and neighborhood relations. From an environmental management perspective, critical issues are soil type, slope, and the nature of the buffer between the site and surface or groundwater resources (Richard, 1996). Since NO_3-N and other nutrients move through the soil and into streams as subsurface flow, or leach down to the groundwater (Tiquia et al., 2002; Garrison et al., 2001), soil permeability is an important factor that impacts windrow composting site design. Consequently, for some windrow composting facilities, a working surface of gravel, compacted sand, oiled stone, or even asphalt or concrete may be appropriate (Richard, 1996).

Sikora and Francis (2000) found lime and fly ash materials produced a hardened, nearly impervious surface layer capable of supporting equipment normally used at a windrow composting facility. They also found constructing a 0.73 ha (1.80 ac) windrow composting pad from lime and fly ash materials was approximately 28 percent of the cost of a comparable-size 15 cm (6 in)-thick concrete pad. Another potential benefit of fly ash and lime composting pad materials is the P-sorbing properties reported by many researchers (Dou et al., 2003; Boruvka and Rechcigal, 2003; Lau et al., 2001; Brauer et al., 2005; DeLaune et al., 2006; Penn and Bryant, 2006). Dou et al. (2003) found fly ash reduced soluble P by 60 percent from converting H_2O-P in dairy manure to $NaHCO_3$-P, a fraction less vulnerable to runoff losses. Significant quantities of Al_2O_3 and CaO also were found in fly ash samples (Pathan et al., 2003), of which either compound can react with PO_4-P. For this dissertation study, approximately 390 m^3 (13,773 ft^3) of fly ash was provided free of charge by a local electric utility power generating station for composting pad construction.

This manuscript focuses primarily on documenting the effects of windrow composting and VFS buffers on runoff quantity and quality. However, windrow composting and VFS buffer effects can vary with the complex soil-water environment and different field conditions. These conditions include structure and species of VFS buffer vegetation, compost material, soil type, soil texture, fly ash composting pad material, type of contaminant, slope of the runoff area, and activities on the runoff area. The primary objective of this study was to quantify the effects of windrow composting practices and VFS buffers on losses of runoff (RO), runoff percent of rainfall (RO%), total solids (TS), nitrate-nitrogen (NO_3-N), ortho-phosphorus (PO_4-P), and total-phosphorus (TP) during natural rainfall events. Critical consideration also was directed towards potential fly ash composting pad effects on runoff.

Materials and Methods

The study site was located at the Iowa State University Dairy Teaching Farm near Ames, central Iowa, USA (42° 00.564' N, 93° 39.267' W). The study site total area was 0.25 ha (0.62 ac) and was comprised of nine plots, each 6 m x 46 m (20 ft x 150 ft). The VFS buffer research plot area was selected on uneven terrain with an average slope of 5 percent. Dominant vegetation included 75 percent smooth brome (*Bromus inermis* Leyss.) and 25 percent switchgrass (*Panicum virgatum* L.) with a trace of mixed broadleaf species. Smooth brome occupied approximately 75 percent of each 1:1 VFS buffer plot, primarily in the upslopes, and approximately 100 percent of each 1:0.5 VFS buffer plot in the upslopes. Switchgrass in the downslope areas occupied approximately 25 percent of each 1:1 VFS buffer plot, but only a trace was observed in the 1:0.5 VFS buffer plots. The average tiller population for VFS buffers was estimated at 2.7M tillers/ha. Tiller population was determined using a method from Arora et al. (2003). The tiller density value from this dissertation study contrasts with 9M tillers/ha (Arora et al., 2003) and 50M tillers/ha (Brueland, et al., 2003) from two other central Iowa VFS buffer research sites with similar vegetation types.

The major soil association at the research site is the Clarion-Webster-Nicollet association, with the minor soil association of Hayden-Lester-Storden in the area. All soils were formed in glacial till and local alluvium from till, with Clarion loam (a fine-loamy, mixed, mesic Typic Hapludolls) the dominant soil at the research site (Dewitt, 1984). The upslope composting pad surface area of the site was comprised of fly ash, a by-product of combustion from coal-fired power plants provided by Alliant Energy, Inc., Madison, Wisconsin, USA. The 0.13 ha (0.32 ac) composting pad area was constructed by machine grading to approximately a 2 percent slope, and fly ash was hydro-compacted to a depth of 30.48 cm (12 in).

This study focused on the effects of windrow composting practices and VFS buffers on runoff volume, sediment, and nutrient transport under natural rainfall conditions. Runoff data were collected from six events during 2002-2004. The composting period was based on 60-day durations during a particular research season, occurring approximately during the June-July early season (ES) and August-September late season (LS) time periods. The 2002 project year included one LS composting period, 2003 included one ES composting period, and 2004 included both ES and LS composting periods. Compost windrows were turned with tractor-assisted elevating-face conveyor and rotary drum flail type compost turning implements on a weekly basis for the first two weeks and bi-weekly for the remainder of the 60-day composting period. Compost samples also were randomly collected on a periodic basis for evaluating dairy manure compost characteristics (nutrients, moisture, and air-filled porosity), conducting nutrient mass balance analysis, and comparing these data to runoff quantity and quality.

Runoff data were analyzed for RO (mm), RO% (percent), TS (g), NO_3-N (mg/L), PO_4-P (mg), and TP (mg) losses from natural rainfall events. Runoff treatments were comprised of three compost windrow:VFS buffer area ratios that included 1:1, 1:0.5, and 1:0 (no buffer) control. The 1:1 and 1:0.5 area ratios represented a 6 m x 23 m (20 ft x 75 ft) fly ash compost pad area compared to equal and one-half size VFS buffer areas, respectively. All treatments had three replications for a total of nine runoff plots distributed in a randomized complete block design. Both compost windrow and VFS buffer plots used water-filled vinyl firehoses and 38 cm (15 in)-wide sheet metal borders, respectively, to minimize cross-contamination from adjacent plots. The firehoses, which could be drained quickly, were used in place of conventional sandbags to expedite the removal/replacement process for compost sampling and turning operations.

A tipping-bucket flow meter system (Hansen and Goyal, 2001) was used to measure and collect runoff from each plot after a rainfall event. A perforated four-inch diameter polyvinyl chloride (PVC) pipe collector was used at the downslope end of each VFS buffer area to direct runoff to the tipping-bucket system through 6 m-30 m (20 ft-98 ft)-long PVC flow pipes. The runoff samples were collected in 19-L (5-gal) plastic tanks through a plastic tube connected to an orifice in the 90° elbow at the end of the flow pipe for each runoff unit. Data loggers (Onset Computers Inc., Massachusetts, USA) connected to magnetic switches were used to measure tips for the tipping-bucket units. Runoff samples were collected after rainfall events of approximately 25 mm (1 in) or greater, and refrigerated until analysis at the Department of Agricultural and Biosystems Engineering Water Quality Laboratory, National Swine Research and Information Center, Iowa State University, Ames, Iowa, USA.

RO volume was determined from the tipping-bucket units and converted to equivalent depth in mm across each VFS buffer runoff plot. TS concentrations (g/kg) in runoff were measured using a gravimetric oven-drying method (Standard Methods, 1998). NO_3-N concentrations (mg/L) were analyzed by the automated flow injection cadmium reduction method using a Lachat Quickchem 2000 Automated Ion Analyzer system (Standard Methods, 1998). PO_4-P concentrations (mg/L) were analyzed by the automated flow injection ascorbic acid method using a Lachat Quickchem 2000

Automated Ion Analyzer system. TP concentrations (mg/L) also were determined from filtered runoff samples using the ascorbic acid method (Hach Company, 2002). All TS and nutrient (NO_3-N, PO_4-P, and TP) concentrations were converted to total losses units of g and mg, respectively. The significance among treatments was determined by using SAS software (SAS Institute, 2004). The GLM Procedure and LSMEANS Test were used to analyze differences among the VFS buffer treatment means at the 95 percent probability level.

Results and Discussion

Runoff Analysis and VFS Buffer Performance

There were a total of six rainfall events during 2002-2004 early season (ES) and late season (LS) composting periods that were used for analysis in this study. Runoff data were analyzed for RO, RO%, TS, NO_3-N, PO_4-P, and TP losses from natural rainfall events. This included event dates, event numbers (E1-E6), and rainfall depths for composting periods 2002-LS (8-5-02E1/35 mm [1.4 in]); 2003-ES (6-25-03E2/81 mm [3.2 in], 7-5-03E3/61 mm [2.4 in]); 2004-ES (7-3-04E4/46 mm [1.8 in]); 2004-LS (8-26-04E5/33 mm [1.3 in], 9-6-04E6/46 mm [1.8 in]). This manuscript discusses average total losses data values of the individual events for each ES and LS composting period during the three project years: 2002-LS (total event rainfall = 35 mm [1.4 in]), 2003-ES (total event rainfall = 142 mm [5.6 in]), and 2004-ES (total event rainfall = 46 mm [1.8 in]), 2004-LS (total event rainfall = 79 mm [3.1 in]).

Runoff analysis results in Figures 1-6 show significantly higher losses ($p < 0.05$) of RO, RO%, TS, NO_3-N, PO_4-P, and TP, respectively, from the 1:0 (no buffer) control treatments for all composting periods. The 1:1 VFS buffers reduced levels of RO, RO%, TS, NO_3-N, PO_4-P, and TP by 98, 98, 98, 98, 97, and 96 percent, respectively. The 1:0.5 VFS buffers reduced levels by 93, 93, 94, 94, 93, and 90 percent, respectively. The overall average surface runoff loss reductions were 98 and 93 percent for the 1:1 and 1:0.5 VFS buffers, respectively, compared to the 1:0 control plots. Figures 1-6 also show the 1:1 and 1:0.5 VFS buffer treatments were not significantly different ($p < 0.05$). The

1:1 and 1:0.5 VFS buffer plots were 23m and 12 m (75 ft and 37.5 ft) in length, respectively. These VFS buffer performance results are similar to findings from other researchers. Edwards et al. (1997) and Lim et al. (1998) found concentrations of several surface runoff contaminants were significantly reduced in approximately 6 m (20 ft)-long VFS buffers, which ranged in lengths from 0-12 m (0-39 ft) and 0-18.3 m (0-60 ft), respectively. Arora et al. (2003) also determined a 30:1 (drainage area:VFS buffer area ratio) VFS buffer area could perform as well as a larger 15:1 VFS buffer area in significantly reducing agricultural herbicides in runoff, requiring less land removed from production to achieve desired results.

Figures 1, 2, and 3 show average RO, RO%, and TS losses, respectively, in surface runoff from the windrow composting/VFS buffer site. These results indicate the 2002-LS and 2003-ES 1:0 control treatments are significantly higher ($p < 0.05$) than the 2002-LS and 2003-ES 1:1 and 1:0.5 VFS buffer treatments. Figures 1-3 also indicate the 2002-LS and 2003-ES 1:0 control treatments are significantly higher ($p < 0.05$) than all VFS buffer treatments in the 2004-ES and 2004-LS composting periods. Since antecedent moisture conditions were minimal for the 2002-LS composting period (< 12 mm [0.5 in] rainfall 25 days before the 35 mm [1.4 in] rainfall event 8-5-02E1), the higher volume of runoff compared to the 2004 composting periods may be attributed to the more impervious surface condition of the fly ash shortly after composting pad construction in 2002. Although composting pad infiltration in 2003 also may have been structurally limited compared to 2004, the higher total rainfall and antecedent moisture conditions for 2003 (142 mm [5.6 in] combined rainfall total with > 50 mm [2 in] within seven days of rainfall event 7-5-03E3) probably elevated the 1:0 control plot runoff levels. For the 2004 composting periods, the significantly reduced runoff levels in the 1:1, 1:0.5, and 1:0 treatments may be due to freeze/thaw action that results in preferential flow cracks in fly ash and soil materials.

Other action that may have affected the fly ash composting surface during 2002-2004 came from various mechanized implements used for manure and compost transporting, turning, and sampling operations. This grinding and scraping action resulted in surface compaction and deformation, accelerating the observed accumulation of fly ash granules at the downslope end of the compost pad throughout the three-year project period. Although composting pad surface compaction during the composting periods may have caused a reduction in runoff infiltration, the accumulation of fly ash granules downslope may have resulted in increased runoff absorption. Punjab Agriculture University researchers reported the application of fly ash as a soil amendment was found to increase the available water content of loamy sand soil by 120 percent and of sandy soil by 67 percent (PAU, 1993).

Figure 4 shows average NO_3-N total losses in runoff for 1:1, 1:0.5 VFS buffer, and 1:0 (no buffer) control treatments. The 2003-ES 1:0 control plot NO_3-N losses were significantly higher ($p < 0.05$) than all other treatments and composting periods. These NO_3-N losses roughly correspond to the event rainfall totals for each composting period, but also may be attributed to the variable nature of NO_3-N in runoff reported by other researchers. Seymour and Bourdon (2003) found NO_3-N concentrations varied by orders of magnitude in dairy manure windrow compost leachate, with lesser NO_3-N concentrations and variability in runoff. They determined the variability to be a function of compost material age, compost process maturity, type of compost manure, and rainfall intensity and duration. This dissertation study used dairy manure for compost windrows in 2002 and 2003, and, due to availability, a mixture of horse, sheep, and beef manure was used for both ES and LS composting periods in 2004.

Figures 5 and 6 represent PO_4-P and TP runoff losses, respectively, for the 1:1, 1:0.5 VFS buffer, and 1:0 (no buffer) control treatments. These results show significantly higher losses ($p < 0.05$) for the 1:0 control plots compared to the 1:1 and 1:0.5 VFS buffer treatments. These results also indicate significantly lower ($p < 0.05$) losses in the 1:0 control plots for 2004 ES and LS composting periods compared to 2002 and 2003. Figures 7 and 8 show PO_4-P and TP runoff concentrations, respectively, for the 1:1, 1:0.5 VFS buffer, and 1:0 (no buffer) control treatments. These results are relatively lower than some other research findings. Seymour and Bourdon (2003) reported that P concentrations varied less than N species, but P tended to have higher concentrations in leachate compared to runoff. They found average PO_4-P concentrations for leachate and runoff were 21 and 15 mg/L, respectively. Average PO_4-P runoff concentrations from this dissertation study for all composting periods for the 1:1, 1:0.5 VFS buffers, and 1:0 (no buffer) control (Figure 7) were 5 mg/L, 6 mg/L, and 3 mg/L, respectively.

Figure 7 also shows the 2004-LS composting period PO_4-P average concentration for the 1:0 control plots were significantly lower ($p < 0.05$) than the 1:1 and 1:0.5 VFS buffer average concentrations. Given the potential fly ash P-reduction effect remains equal for all runoff treatments, this may suggest the VFS buffer vegetation could be contributing PO_4-P to runoff. Haan et al. (2007) reported that grazing (vegetation removal) stimulates new shoot and root growth, and non-grazed pastures (similar to VFS buffers) can gradually lose their capacity to sequester sediment and nutrients. Steinke et al. (2007) also found TP losses were similar for both prairie and turfgrass VFS buffer species in a study assessing runoff quality and quantity. They also suggested the natural nutrient biogeochemical cycling can result in nutrient loss to surface waters regardless of vegetation type or size in VFS buffers. Although runoff dilution from rainfall and different compost manure and raw materials could affect PO_4-P concentrations and total mass losses, current research findings suggest fly ash can affect P levels in runoff. Consequently, a mass balance analysis was used in determining the difference in mass total losses of NO_3-N, PO_4-P, and other nutrients in the compost windrows for comparison to nutrient losses in surface runoff.

Compost Nutrient Mass Balance Analysis

Nutrient mass balance calculations were conducted using compost (Ahn et al., in prep.) and were compared to surface runoff nutrient losses from the three 1:0 no buffer (control) plots at the windrow composting/VFS buffer research site. The 1:0 control plots were used exclusively in this analysis to limit the effects of rainfall infiltration and runoff to the compost windrows and fly ash composting plot areas. Quantity and composition of compost material before and after the composting period are shown in Table 1. Differences of nutrient content based on compost and runoff mass balance calculations are shown in Table 2.

Dairy manure (2002 and 2003), horse manure, and a dairy/horse/sheep manure mixture (2004) were composted in full-scale windrow systems, each trial containing nine windrows. These samples were collected three times during the entire composting period at 0, 30, and 60 days after compost windrow construction. A total of three, waist-height "grab-sample" runs per windrow were conducted, with a collection of about a 3 L volume of samples for nutrient analysis. The amounts and composition of the manure before and after composting are given in Table 1.

The loss of dry matter (DM), total carbon (TC), total nitrogen (TN), TP, total potassium (TK), NO_3-N and PO_4-P was calculated using the mass balance operation in the following Equation 1:

$$\text{Total loss} = C_{before} \text{ X } Q_{before} - C_{after} \text{ X } Q_{after} \tag{1}$$

From Equation 1, C_{before} and C_{after} are the component concentration (mg/kg or percent, dry base [d.b.]); Q_{before} and Q_{after} are the mass (kg, d.b.) of the compost windrow at the beginning and end of a composting period. The reduction in DM content was between 7 and 9 percent of the initial DM content. The DM reduction is mainly caused by microbial biodegradation of organic material (24-38 percent reduction of TC) and the solid material loss through surface runoff. The total nitrogen (TN) losses were between 13 and 35 percent of the initial TN mass volume. The pathway of N loss from the composting piles was probably through emissions of ammonia (NH_3) and, to a lesser extent, through nitrous oxide species (NOx) emissions. Generally, NH_3 production increases during the early stage of the composting period, and then is biologically transformed into NO_3-N/NO_2-N via nitrification. Due to this biochemical conversion, a nitrate concentration increase was observed in this study. This variability of NO_3-N concentrations also parallels the findings of Seymour and Bourdon (2003).

Levels of TP and TK did not significantly change during the composting process since they are non-volatile nutrients and are not lost to the atmosphere. Generally, TP and TK can leach out of the compost windrows with runoff, and the composting process does not significantly affect TP and TK levels. A PO_4-P reduction of 26-41 percent occurred during the composting process compared to the runoff fraction of PO_4-P losses ranging from 0.1-0.4 percent. These mass balance and runoff nutrient analysis results indicate PO_4-P was removed from the runoff stream in a higher proportion than some similar studies (Seymour and Bourdon, 2003). Results from this dissertation study indicate the PO_4-P in runoff from the compost windrows may have been absorbed or converted to more stable P compounds, possibly by the fly ash composting pad material.

Summary and Conclusion

This study quantifies the effects of windrow composting practices and VFS buffers on losses of runoff (RO), runoff percent of rainfall (RO%), total solids (TS), nitrate-nitrogen (NO_3-N), ortho-phosphorus (PO_4-P), and total-phosphorus (TP) during natural rainfall events. Runoff data from six events were collected during June-July (early season) and August-September (late season) 60-day composting periods from 2002-2004 at an Iowa State University research farm near Ames, central Iowa, USA. Results from the study indicate significantly higher levels ($p < 0.05$) of RO, RO%, TS, NO_3-N, PO_4-P, and TP from the 1:0 control plots compared to the 1:1 and 1:0.5 plots. Results also show the 1:1 and 1:0.5 VFS buffer treatments were not significantly different ($p < 0.05$). Average runoff loss reductions from the 1:1 and 1:0.5 plots were 98 and 93 percent, respectively, compared to the 1:0 control plots. These results reflect the effectiveness of VFS buffers for reducing runoff and contaminant losses from a windrow composting site.

Compost nutrient mass balance analysis results indicate 26-41 percent of PO_4-P was lost from the compost windrows during the 2004 composting periods. However, only 0.1-0.4 percent of PO_4-P was lost to runoff from the 1:0 control plots. We hypothesize the significantly lower PO_4-P losses in runoff may be attributed to potential chemical and physical effects of the fly ash composting pad material. Political and social interests are increasingly directed towards adopting more environmentally responsible strategies that reclaim or recycle certain waste materials and protect natural resources. Consequently, future research efforts could include a comparison of fly ash to other composting pad surface materials to more thoroughly evaluate the efficacy of this industrial by-product in reducing offsite runoff and contaminant transport from windrow composting facilities.

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Table 1. Quantity and composition of compost material before and after composting at the windrow composting/VFS buffer research site at the ISU Dairy Teaching Farm, Ames, central Iowa, USA (N=27; * N=9).

		2002-LS	2003-ES	2004-ES	2004-LS
	Manure type	Dairy	Dairy	Horse	Dairy/Horse/Sheep
Before	Amount (kg, w.b.)*	25,799±1,315	21,239±2,409	9,738±1,860	8,948±248
	Moisture content (%, w.b.)	73.7±3.0	69.8±1.9	59.4±1.9	62.6±2.9
	Volatile solids (%, d.b.)	43.3±5.0	39.0±2.4	44.7±4.2	53.0±2.5
	TC (%, d.b.)	18.7±2.0	17.6±1.7	18.9±1.6	26.9±2.9
	TN (%, d.b.)	2.0±0.1	1.4±0.1	1.3±0.1	1.9±0.1
	TP (mg/kg, d.b.)	4,663±541	5,070±900	4,611±829	6,586±1,473
	TK ((mg/kg, d.b.)	15,874±2,392	25,475±2,781	23,140±2,281	14,389±2,326
	NO_3-N (mg/kg, d.b.)	-	-	548±136	755±165
	PO_4-P (mg/kg, d.b.)	-	-	332±49	599±116
After	Amount (kg, w.b.)	14,904±1,339	17,704±1,647	9,034±334	7,509±313
	Moisture content (%, w.b.)	35.9±4.1	61.5±3.2	50.2±3.2	49.3±2.2
	Volatile solids (%, d.b.)	38.9±2.3	33.0 ±2.1	39.4±2.7	49.1±1.9
	TC (%, d.b.)	15.4±2.1	12.0±1.1	14.0±2.5	22.3±1.5
	TN (%, d.b.)	1.4±0.1	1.0±0.1	1.0±0.1	1.8±0.1
	TP (mg/kg, d.b.)	4,749±477	2,810±271	4,486±341	7,453±1,211
	TK (mg/kg, d.b.)	13,208±1,635	14,023±1,730	9,240±1,312	12,932±1,292
	NO_3-N (mg/kg, d.b.)	-	-	663±57	928±94
	PO_4-P (mg/kg, d.b.)	-	-	215±20	482±77

Table 2. Differences of nutrient content based on compost and runoff mass balance calculations for the windrow composting/VFS buffer research site at the ISU Dairy Teaching Farm, Ames, central Iowa, USA (* Runoff fraction of total PO_4-P loss).

		2002-LS	2003-ES	2004-ES	2004-LS
Compost	Dry matter (kg)	407	445	291	220
	TC (kg)	249	331	204	181
	TN (kg)	39.6	24.3	12.9	6.8
	TP (kg)	1.5	12.5	1.7	-
	TK (kg)	20.5	63.2	49.0	7.0
	NO_3-N (kg)	-	-	-0.19	-0.29
	PO_4-P (kg)	-	-	0.45 (46%)	0.44 (21%)
Runoff	Dry matter (kg.)	6.4	11.7	0.7	1.4
	TP (g)	10.4	19.3	0.7	2.7
	NO_3-N (g)	0.6	104.7	2.3	254.4
	PO_4-P (g)	10.5	15.6	0.4 (0.1%)*	1.8 (0.4%)

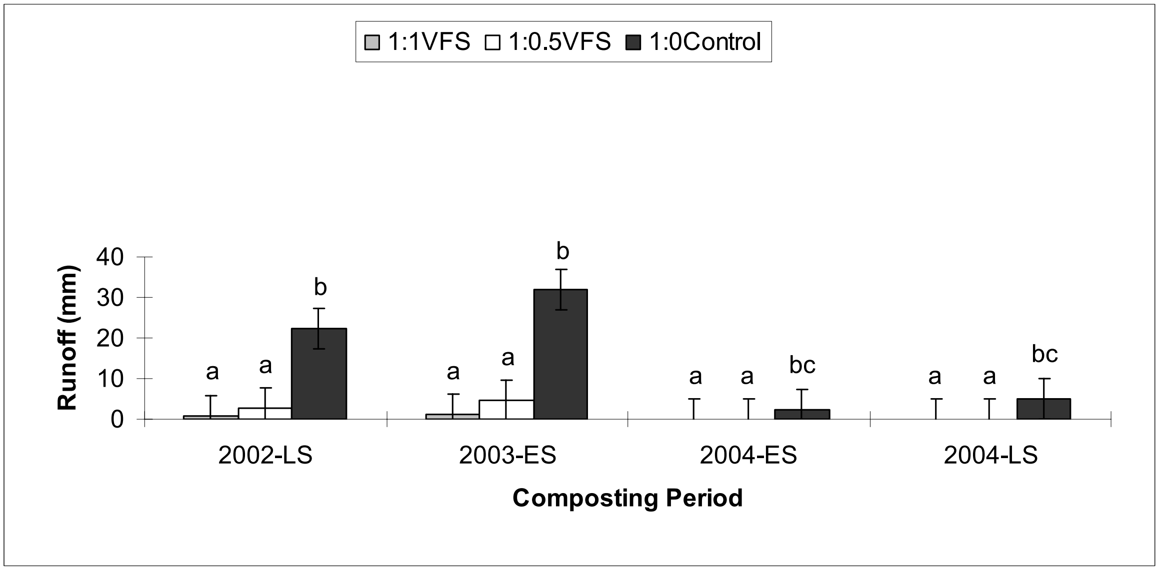

Figure 1. Effects of windrow composting practice and VFS buffer treatments (1:1, 1:0.5, and 1:0 [no buffer] control composting area:VFS buffer area ratios) on average runoff depth (mm) for 2002-2004 early season (ES) and late season (LS) composting period rainfall events at the ISU Dairy Teaching Farm, Ames, central Iowa, USA. Significant treatment differences within and among composting periods are indicated by different letters (b and c, respectively) and error bars represent one standard deviation.

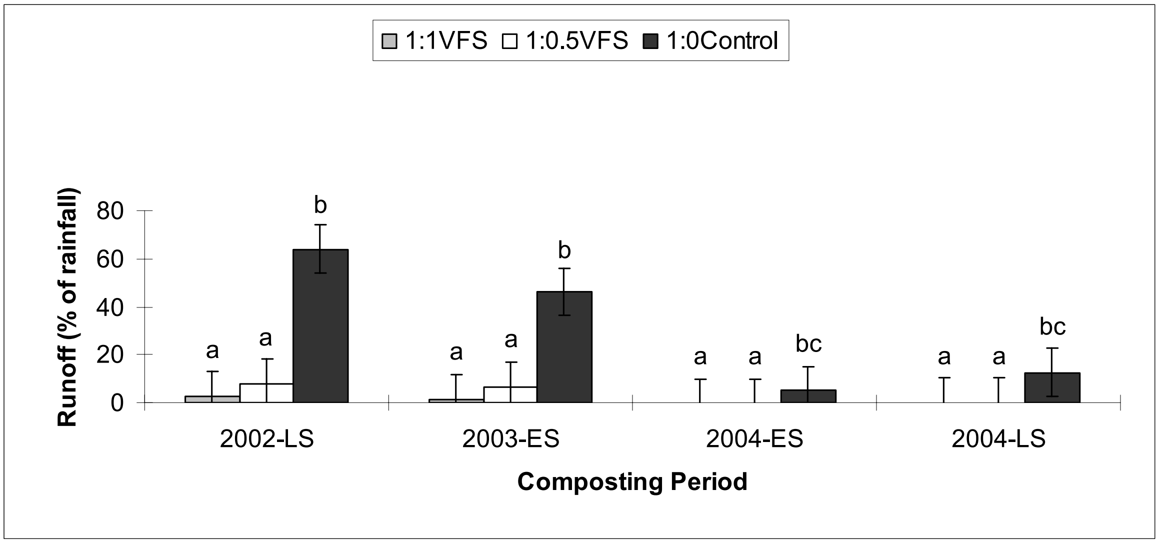

Figure 2. Effects of windrow composting practice and VFS buffer treatments (1:1, 1:0.5, and 1:0 [no buffer] control composting area:VFS buffer area ratios) on average runoff percent of rainfall for 2002-2004 early season (ES) and late season (LS) composting period rainfall events at the ISU Dairy Teaching Farm, Ames, central Iowa, USA. Significant treatment differences within and among composting periods are indicated by different letters (b and c, respectively) and error bars represent one standard deviation.

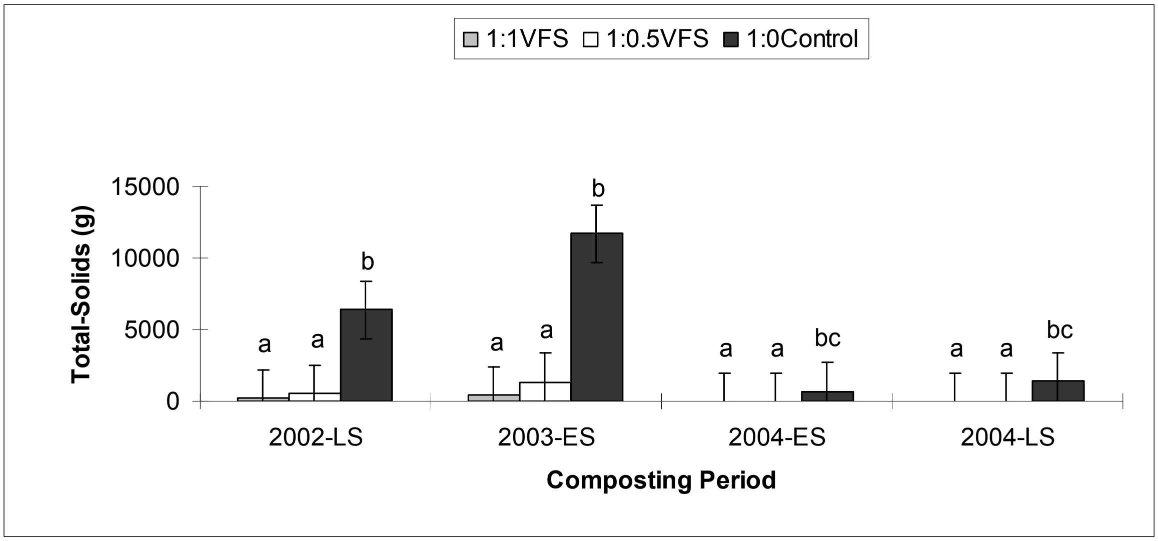

Figure 3. Effects of windrow composting practice and VFS buffer treatments (1:1, 1:0.5, and 1:0 [no buffer] control composting area:VFS buffer area ratios) on average total-solids surface runoff losses (g) for 2002-2004 early season (ES) and late season (LS) composting period rainfall events at the ISU Dairy Teaching Farm, Ames, central Iowa, USA. Significant treatment differences within and among composting periods are indicated by different letters (b and c, respectively) and error bars represent one standard deviation.

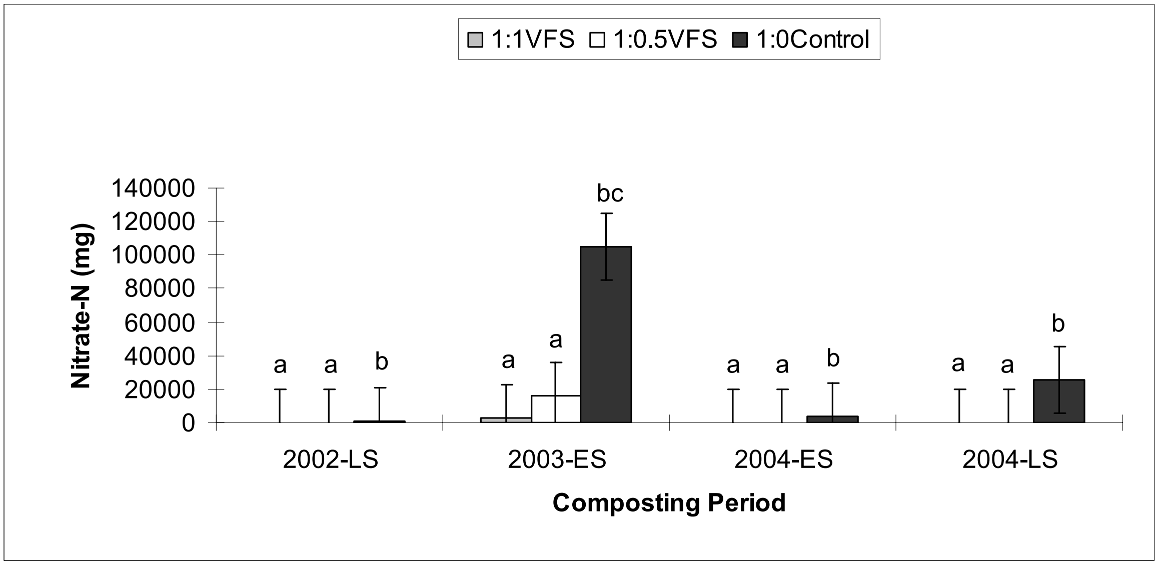

Figure 4. Effects of windrow composting practice and VFS buffer treatments (1:1, 1:0.5, and 1:0 [no buffer] control composting area:VFS buffer area ratios) on average NO_3-N surface runoff losses (mg) for 2002-2004 early season (ES) and late season (LS) composting period rainfall events at the ISU Dairy Teaching Farm, Ames, central Iowa, USA. Significant treatment differences within and among composting periods are indicated by different letters (b and c, respectively) and error bars represent one standard deviation.

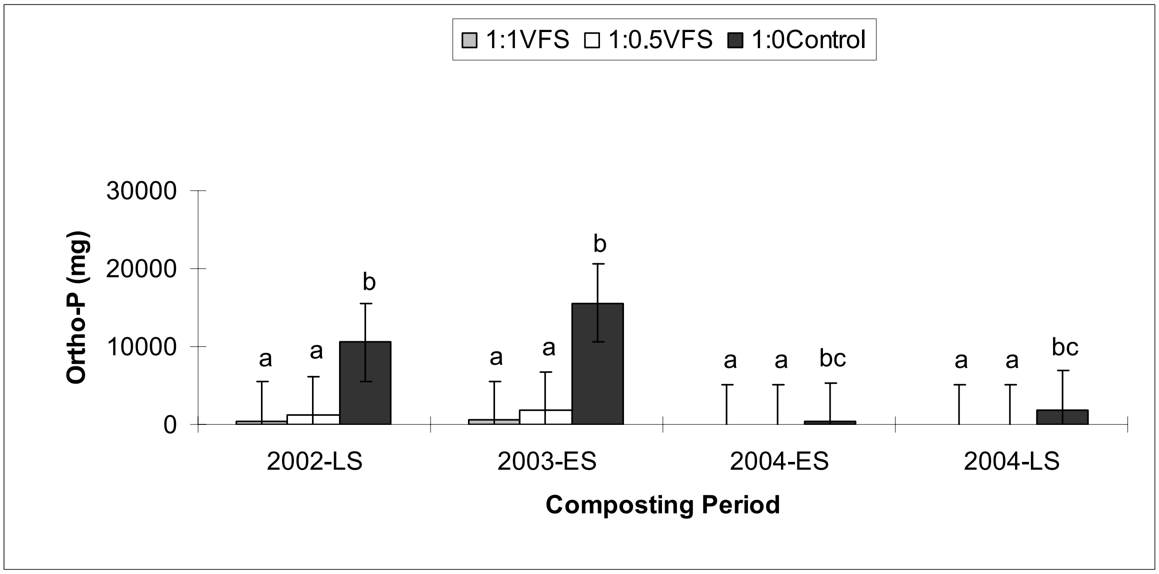

Figure 5. Effects of windrow composting practice and VFS buffer treatments (1:1, 1:0.5, and 1:0 [no buffer] control composting area:VFS buffer area ratios) on average PO_4-P surface runoff losses (mg) for 2002-2004 early season (ES) and late season (LS) composting period rainfall events at the ISU Dairy Teaching Farm, Ames, central Iowa, USA. Significant treatment differences within and among composting periods are indicated by different letters (b and c, respectively) and error bars represent one standard deviation.

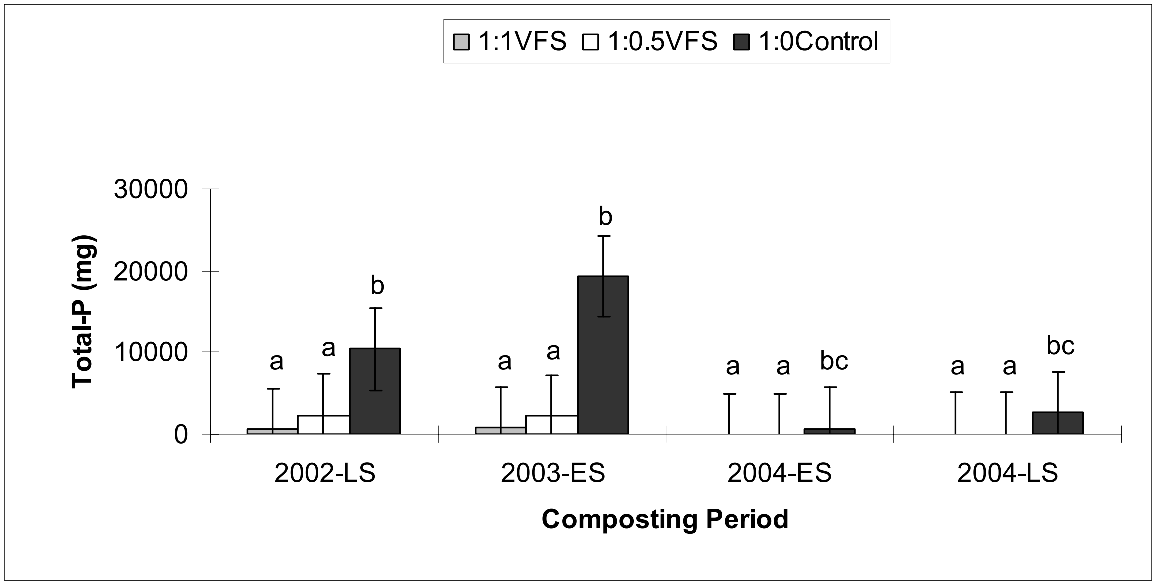

Figure 6. Effects of windrow composting practice and VFS buffer treatments (1:1, 1:0.5, and 1:0 [no buffer] control composting pad area:VFS buffer area ratios) on average total-P surface runoff losses (mg) for 2002-2004 early season (ES) and late season (LS) composting period rainfall events at the ISU Dairy Teaching Farm, Ames, central Iowa, USA. Significant treatment differences within and among composting periods are indicated by different letters (b and c, respectively) and error bars represent one standard deviation.

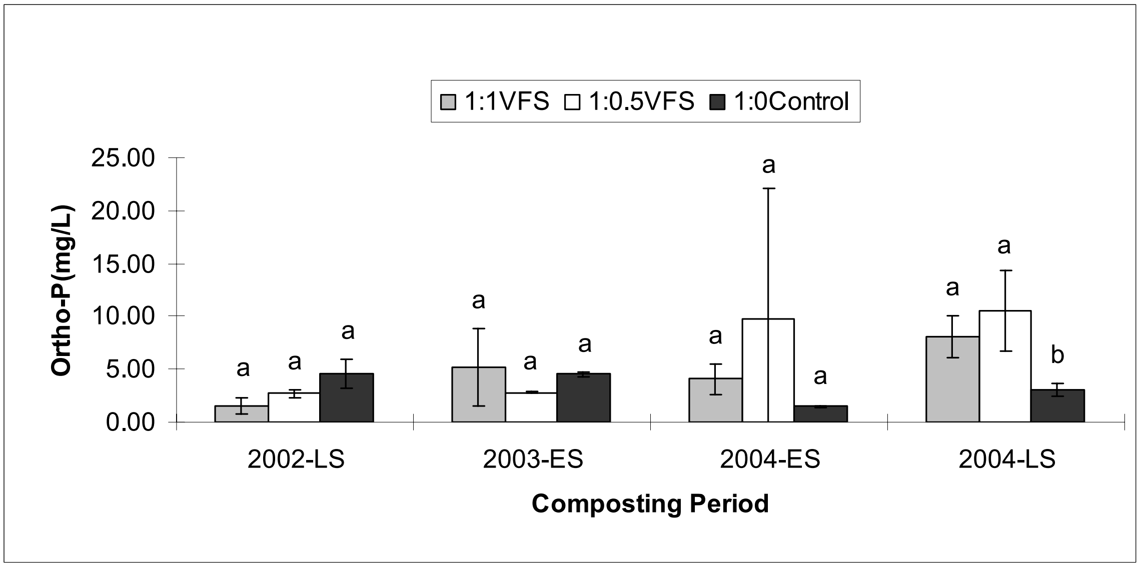

Figure 7. Effects of windrow composting practice and VFS buffer treatments (1:1, 1:0.5, and 1:0 [no buffer] control composting pad area:VFS buffer area ratios) on average PO_4-P surface runoff concentrations (mg/L) for 2002-2004 early season (ES) and late season (LS) composting period rainfall events at the ISU Dairy Teaching Farm, Ames, central Iowa, USA. Significant treatment differences within composting periods are indicated by different letters (b) and error bars represent one standard deviation.

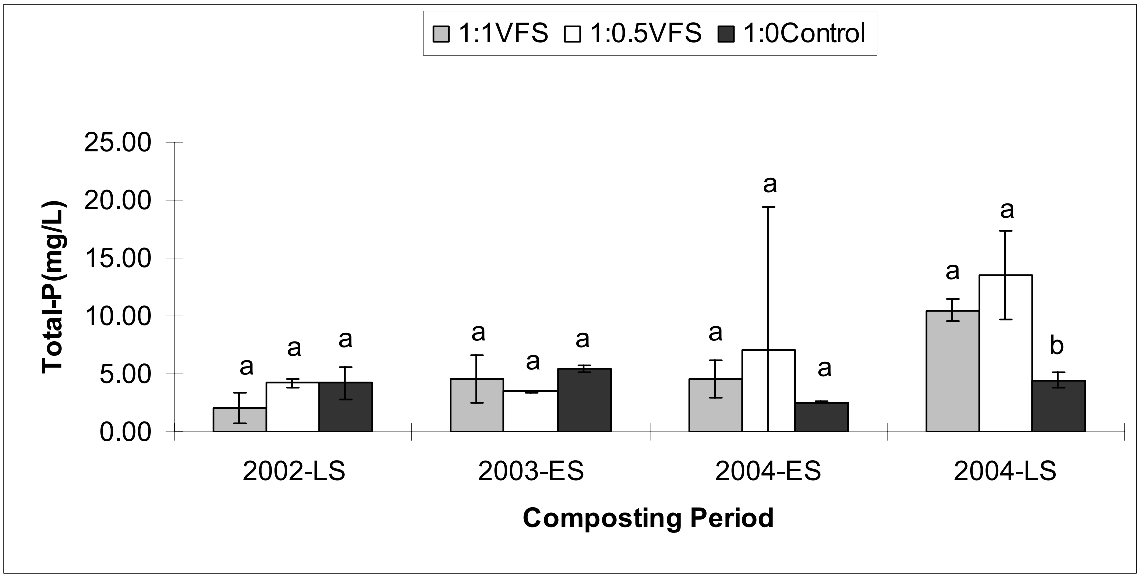

Figure 8. Effects of windrow composting practice and VFS buffer treatments (1:1, 1:0.5, and 1:0 [no buffer] control composting pad area:VFS buffer area ratios) on average total-P surface runoff concentrations (mg/L) for 2002-2004 early season (ES) and late season (LS) composting period rainfall events at the ISU Dairy Teaching Farm, Ames, central Iowa, USA. Significant treatment differences within composting periods are indicated by different letters (b) and error bars represent one standard deviation.

CHAPTER 5: HYDROLOGIC MODELING OF RUNOFF FROM A WINDROW COMPOSTING SITE WITH VEGETATIVE FILTER STRIP BUFFERS

A paper to be submitted to *Compost Science and Utilization*

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Abstract

This research calibrated and validated a hydrologic model for predicting runoff volume losses from a windrow composting site with VFS buffers. The site also included a composting pad surface constructed of fly ash obtained from a local coal-fired power generating station. Observed runoff and physical attribute data from six rainfall events during 2002-2004 at a central Iowa windrow composting research site were used in the model evaluation. These data included average runoff volumes from three compost windrow:VFS buffer area ratio treatments (1:1, 1:0.5, and 1:0 [no buffer] control), each replicated to comprise a total of nine plots. Calibration simulations indicated good agreement of simulated runoff data to observed data for all 1:1, 1:0.5, and 1:0 (no-buffer control) VFS buffer treatments. The 1:0 (control) treatment plots also indicated good data agreement for all calibration and validation simulations. However, validation simulations resulted in overpredictions for the 1:1 and 1:0.5 VFS buffer runoff volumes that were most significant in the 2004 late rainfall events period. Results from this initial study with limited data indicated that alternatives to soils data-derived VFS buffer surface infiltration and runoff functions should be considered to potentially improve model prediction accuracy. These results and other research findings suggest that possibly the fly ash composting pad material and age of the research site may have contributed to the overpredicted 1:1 and 1:0.5 VFS buffer runoff validation simulation results.

Introduction

Land application of manure to agricultural fields can elevate runoff concentrations of nutrients such as nitrogen (N), carbon (C), and phosphorus (P) (Westerman *et al*. 1987;

Edwards and Daniel 1993; Heathwaite *et al*. 1998). Surface runoff of nutrients from agricultural fields is a major source of water pollution in surface waters in the US (Parry 1998). One strategy to minimize the adverse effects of livestock manure on the environment is windrow composting. Windrow composting consists of placing manure and other raw materials in long narrow piles or windrows which are agitated or turned on a regular basis (Rynk *et al*. 1992). Studies have shown that composted manure was less hazardous to the environment (Eghball and Power 1999; Vervoort *et al*. 1998) and much of the mineral N was converted to more stable organic forms (Rynk *et al*. 1992).

Vegetative filter strip (VFS) buffers are bands of vegetation located downslope of cropland or other potential pollutant source areas. These buffer strips provide erosion control and filter nutrients, pesticides, sediment, and other pollutants from agricultural runoff by reducing the sediment carrier and through interception-adsorption, infiltration, and degradation of pollutants dissolved in water (Dillaha *et al*. 1989). VFS buffers have been suggested as a best management practice (BMP) that has been shown to reduce sediment and nutrient losses in a range of agricultural settings, including crop fields and feedlots (Magette *et al*. 1989; Patty *et al*. 1997). The effectiveness of VFS buffers as BMPs in controlling pollutants from cropland also has been assessed by many researchers (Dillaha *et al*. 1985; Mickelson and Baker 1993; Lee 2000). These researchers found that VFS buffers have potential for significantly improving the water quality of runoff.

Hydrologic models have been used for over 30 years to simulate sediment and nutrient transport in surface runoff through VFS buffers (Tollner *et al*. 1976; Delgado *et al*. 1992; Srivastava *et al*. 1998). However, few reports exist regarding hydrologic models for predicting runoff losses from windrow composting sites. Governo (2001) developed a spreadsheet-based computer program to assist in the design phase of windrow composting facilities, but did not include a hydrologic modeling component. Tollner and Das (2004) evaluated hydrologic models that applied the NRCS Curve Number method for predicting runoff from a yard waste windrow composting site. Although this research effort described a hydrologic modeling approach for windrow composting sites, it does not include a runoff modeling function for VFS buffers. Wilson *et al*. (2004) reported that approximately 68 percent of rainfall incident on saturated compost windrows from both natural and simulated rainfall events resulted in runoff, using the 0.68 value as a runoff coefficient.

This manuscript focuses on the calibration and validation of a computer hydrologic model for simulating surface runoff volume from a windrow composting site with VFS buffers. Although the hydrologic model used in this research effort includes input/output components for predicting sediment and nutrient transport, this study only uses the infiltration and runoff functions. This is largely due to the requirement of additional compost bioconversion and nutrient dynamics data. Srivastava *et al*. (1998) also reported that accurate simulation of infiltration and runoff is an important initial step for accurate prediction of contaminant concentration mass transport.

Materials and Methods

WCVFS Model Description

The hydrologic model calibrated and validated in this study was modified from a Vegetated Treatment Area (VTA) model developed at Iowa State University (Wulf and Lorimor 2005) that simulates runoff from an open feedlot as the effluent progresses down the length of the VTA. This hydrologic model was chosen primarily because of the similarities between livestock feedlots and windrow composting sites. These similarities include the relatively impervious surface of these sites due to animal and machinery traffic and the presence of livestock manure. The model also was chosen due to its versatility of data input and simulation dimensions and the relative ease of model operation. For this study, the VTA hydrologic model will be referred to as the Windrow Composting/VFS (WCVFS) model. The WCVFS model runs in the ModelMaker version 4.0 modeling software environment (ModelKinetix 2000).

The WCVFS model accounts for runoff (either from snowmelt or rainfall) from the compost windrow and composting pad area, direct precipitation falling on the VFS buffer area, and soil infiltration. The model then predicts runoff outflow volume from the end of the VFS buffer. For input parameters, the WCVFS model uses weather data text files to predict runoff volume. The model also uses physical attributes that include VFS buffer size (width, length, and area), soil infiltration rate, soil depth, water table depth, soil slope, and vegetation type (Wulf and Lorimor 2005).

For infiltration and runoff from the compost windrow and pad areas, the WCVFS model uses the NRCS Curve Number Method (Plummer and Woodward 1998) to simulate hydrologic conditions during single rainfall events. This study also uses a laboratory-derived runoff coefficient of 0.63 from a compost cross-section prototype and simulated rainfall (Whitman *et al*. in prep.). The runoff coefficient is the volume of runoff and leachate collected divided by the simulated rainfall total volume (Wilson *et al*. 2004). The WCVFS model also is compatible with the Green-Ampt equation (Green and Ampt 1911) and other infiltration functions. However, Lamont (2006) reported that the NRCS Curve Number method should be confined to single-event modeling (as was done in this study) since it reflects runoff totals based on a 24-hour (daily) duration. For the WCVFS model flow routing component, the model was designed with the VFS buffer broken down into 100 equal segments and routes the flow down the length of the VFS buffer in five-minute increments. In each segment, the model accounts for inflow from the segment immediately upslope, direct precipitation, soil infiltration, and surface outflow onto the surface of the next segment (Wulf and Lorimor 2005). The WCVFS model also is compatible with the kinematic wave flow routing function (Munoz-Carpena *et al*. 1992).

Research Site and Rainfall Data

The study site was located at the Iowa State University Dairy Teaching Farm in Ames, central Iowa, USA (42° 00.564' N, 93° 39.267' W). The study site total area was 0.25 ha (0.62 ac) comprised of nine plots, each 6 m x 46 m (20 ft x 150 ft). The research plot area was selected on uneven terrain with an average slope of 5 percent. Dominant vegetation included 75 percent smooth brome (*Bromus inermis* Leyss.) and 25 percent switchgrass (*Panicum virgatum* L.) and a trace of mixed broadleaf species. Smooth brome occupied approximately 75 percent of each 1:1 VFS buffer plot, primarily in the upslope areas, and approximately 100 percent of the 1:0.5 VFS buffer plots. Switchgrass in the downslopes occupied approximately 25 percent of each 1:1 VFS buffer plot, but only a trace was observed in the 1:0.5 VFS buffer plots. The average tiller population for VFS buffer grass species was estimated to be 2.7M tillers/ha. Tiller population was determined using a method from Arora *et al*. (2003).

The major soil association at the research site is the Clarion-Webster-Nicollet association, with the minor soil association of Hayden-Lester-Storden in the area (Dewitt 1984). All soils were formed in glacial till and local alluvium from till, with Clarion loam (a fine-loamy, mixed, mesic Typic Hapludolls) the dominant soil at the research site and with minor areas of Webster soil (a fine-loamy, mixed, mesic Typic Haplaquolls). The upslope composting pad surface area of the site was comprised of fly ash, a by-product of combustion from coal-fired power plants provided by Alliant Energy, Inc., Madison, Wisconsin, USA. The 0.13 ha (0.32 ac) composting pad area was constructed by machine grading to approximately a 2 percent slope, and fly ash was hydro-compacted to a depth of 30.48 cm (12 in). Three rainfall events during the 2002-2003 early-events (EE) period and three events during the 2004 late-events (LE) composting periods were used for calibrating (C) and validating (V) the WCVFS model. These events, consecutive event numbers (E1-E6), event period (EE-LE), model run (C-V), and rainfall totals include the following event designations: 8-5-02E1EEC/35 mm (1.4 in), 6-25-03E2EEC/81 mm (3.2 in), 7-5-03E3EEV/61 mm (2.4 in), 7-3-04E4LEC/46 mm (1.8 in), 8-26-04E5LEC/33 mm (1.3 in), and 9-6-04E6LEV/46 mm (1.8 in). These rainfall event data also are given in Table 4.

Simulation Procedure and Statistical Analyses

The WCVFS model simulation procedure is initiated by accessing and selecting weather data files from the red cross-hatched "weather" icon at the top center of the model interface screen (Figure 1). This action is followed by responding to a series of user input dialog windows outlined by Wulf and Lorimor (2005). Compost windrow, pad, VFS buffer size parameters, and other physical attributes are either entered manually in each of the remaining dialog windows or can be pre-entered in the user input default mode to allow rapid clicking through the dialog window sequence. Fixed and variable input parameters appear in the following bulleted lists and example input data also are shown in Tables 1-4.

The weather data for the WCVFS model are in text file format organized in a columnar series. Each file contains the following fixed site-specific parameters as a minimum for each rainfall event, and an example weather data file is given in Table 1:

- Time (Julian), year, month and day
- Temperature maximum (Tmax, °F)
- Temperature minimum (Tmin, °F)
- Daily precipitation (in)
- Daily evapotranspiration (in)
- Daily evaporation (in)
- Evaporation coefficient (dimensionless)

The fixed input parameters needed for each soil layer in the soils database of the WCVFS model include the following bulleted list. Actual values used in model calibration and validation simulations are in parentheses, and an example soils data access list is shown in Table 2:

- Soil number (94)
- Soil name (Webster-selected due to model requirement of using the lowest hydraulic conductivity soil in site area)
- Bulk density (1.43 gm/cm^3 [0.052 lb/in^3])
- Wilt point expressed as percent volumetric moisture at 15 atm (1520 kPa [0.185 percent])
- Available water capacity (AWC) (0.132 percent)
- Clay (25.7 percent)
- Sand (37.1 percent)
- Organic carbon (1.58 percent)
- Nitrogen (0.14 percent)
- Depth to bottom of soil layer (84 cm [33 in])

Fixed vegetation input data for running WCVFS model simulations include the following parameters. Actual values used in WCVFS model calibration and validation simulations are in parentheses, and an example vegetation type access list is given in Table 3.

- VFS buffer vegetation number (9)
- VFS buffer vegetation name (bromegrass)
- N uptake high (225 ppm)
- N uptake low (120 ppm)
- P uptake high (26 ppm)
- P uptake low (10 ppm)
- Manning n (0.05)
- Retardance class number (3)
- Plant spacing (0.17 cm [0.065 in])

Fixed physical attribute input data for running WCVFS model calibration and validation simulations include the following parameters:

- Compost windrow length (16 m [52 ft])
- Compost windrow width (2.4 m [8 ft])
- Compost pad length (23 m [75 ft])
- Compost pad width (6 m [20 ft])
- Compost pad average slope (2 percent)
- VFS buffer width (6 m [20 ft])
- VFS buffer average slope (5 percent)
- VFS buffer effective width value entered from user knowledge or calculated by model from vegetation spacing data (80 percent)
- VFS buffer macroporosity as calculated by the model (1)
- Composting site water table seepage rate (0.64 cm/day [0.25 in/day], selected due to model requirement of lowest hydraulic conductivity)

Variable physical attribute input data for running WCVFS model calibration and validation simulations include the following parameter ranges. Some of these variable parameters also are included in Table 4:

- Compost windrow Curve Number (87-95)
- Compost pad Curve Number (66-89)
- VFS buffer length (23 m [75 ft] for 1:1 VFS buffer or 12 m [37.5 ft] for 1:0.5 VFS buffer)
- Composting site seasonal water table (0.5-1.2 m [1.5-4.0 ft])

Hydrologic model calibration and validation during this study was conducted manually as described by Moriasi *et al*. (2006). The calibration process essentially involved adjusting the four variable attribute input parameters (from the previous bulleted list) independently throughout a series of simulations to arrive at simulated runoff volumes that most closely equaled respective observed runoff volumes. These simulations were conducted using rainfall events divided into relatively "wet periods" and "dry periods" (Moriasi *et al*. 2006). The wet periods correspond to the three 2002-2003 events (early-events [EE]) and the dry period corresponds to the three 2004 events (late-events [LE]). Calibration events were designated as early-events calibration (EEC) and late-events calibration (LEC) rainfall events. Initially, both calibration and validation simulations require the 1:1 and 1:0.5 VFS buffer length input parameters of 23 m (75 ft) or 12 m (37.5 ft). The compost windrow Curve Number (CN) was calibrated by adjusting the CN to correspond with a compost windrow runoff volume fraction that equaled a runoff coefficient of 0.63 that was determined from laboratory compost rainfall simulations (Whitman *et al*. in prep.). The composting pad CN was then adjusted to equal the observed 1:0 (no buffer) control treatment average runoff volume. Finally, the seasonal water table depth parameter was adjusted to equal the observed average runoff volume from the 1:1 and 1:0.5 VFS buffer plots. However, the water table depth input parameters entered in the calibration simulations were consistent with Soil Survey (DeWitt 1984) water table depth ranges of 0.3-1.8 m (1-6 ft) or greater for Clarion and Webster soils, respectively, present at the field research site.

The model validation process was conducted using input parameter data for each early-events validation (EEV) and late-events validation (LEV) rainfall event. Compost windrow CN parameters for validation simulations were derived from averaging the CN values used during the calibration process because an average value would approximate the 0.63 runoff coefficient. Composting pad CN for validation simulations was selected for lowest hydraulic conductivity, which is consistent with the model requirement of selecting the soil type at the site with the lowest hydraulic conductivity. This generally involved selecting the highest CN value used during the events period (EE or LE) calibration simulations. Seasonal water table depth input parameters also were selected for validation simulations based on soil type with the lowest hydraulic conductivity, which corresponded to the shallowest water table depth parameter used during an events period calibration simulation process in a single project year. However, for this study the EE events period included two years (2002 and 2003), and the initial 2002 season was conducted shortly after the construction of the fly ash compost pad and field preparation and planting of the VFS buffers. Since these site construction activities resulted in extremely compacted composting pad and VFS buffer surfaces, the seasonal water table input parameter used for the EE validation simulation was averaged over the water table values used during all EE calibration simulations.

Calibration and simulation runoff volume data were compared to observed data using three statistical analyses described by Moriasi *et al*. (2006). Standard regression (R^2) was used in this study and is widely used for model evaluation and describes the degree of collinearity between simulated and measured data. Although the R^2 is a useful statistical criterion, it tends to be oversensitive to outlier values and insensitive to additive and proportional differences between model predictions and measured data (Legates and McCabe 1999) and is not recommended by Moriasi *et al*. 2006. Two other recommended statistical criteria used in this study included the Nash-Sutcliffe Efficiency (NSE) and the RMSE (Root mean square error)-observation Standard deviation Ratio (RSR). The NSE ranges between $-\infty$ and 1 (1 inclusive) with NSE = 1 being the optimal value. Values > 0 indicate "minimal acceptable" performance, whereas values < 0 indicates that the mean observed value is a better predictor than the simulated value. The RSR is calculated as the ratio of the RMSE and standard deviation of measured data. RSR varies from the optimal value of 0, which indicates zero RMSE or residual variation and therefore a perfect model simulation, to a large positive value. The lower the RSR, the lower the RMSE and the better the model simulation performance (Moriasi *et al*., 2006).

Results and Discussion

WCVFS Model Performance and Runoff Overprediction

Numerical observed and simulated runoff volumes (L) from calibration and validation simulations for the 1:1, 1:0.5, and 1:0 VFS buffer treatments, along with event designations and variable input parameters are shown in Table 4. Observed versus simulated runoff volumes for the 1:1, 1:0.5, and 1:0 VFS buffer treatments also are graphically depicted in Figures 2-7. Figures 2 and 3 show good agreement of observed to simulated runoff for early-events (EE) period rainfall events 8-5-02E1EEC and 6-25-03E2EEC, respectively. Figures 4 and 5 also show good agreement of observed versus simulated runoff for late-events (LE) period rainfall events 7-3-04E4LEC and 8-26-04E5LEC, respectively. Figures 8 and 9 indicate R^2 values of 0.99 and 0.99 for the EEC and LEC calibration simulation results, respectively. NSE and RSR values for the EEC and LEC events period simulation results are 0.99 and 0.05, and 0.98 and 0.13, respectively, indicating good agreement of observed to simulated runoff data for both events periods.

Figures 6 and 7 depict observed and simulated runoff volumes for the 7-5-03E3EEV and 9-6-04E6LEV validation simulations. Figure 6 shows reasonable observed versus simulated data agreement in the 1:1 and 1:0 (no buffer control) VFS buffer treatments. However, the 1:0.5 VFS buffer treatment indicates an approximately 1700 L overprediction. Although Figure 7 shows good observed versus simulated runoff data agreement for the 1:0 (no buffer control) treatment plots, the 1:1 and 1:0.5 VFS buffers indicate 2670 L and 2468 L overpredictions, respectively. Figures 10 and 11 indicate R^2, NSE, and RSR values for the EEV and LEV validation simulations, respectively. Figure 10 shows R^2, NSE, and RSR values of 0.65, 0.53, and 0.69, respectively. Moriasi *et al*. (2006) reported that R^2 values greater than 0.50 are typically considered acceptable and model simulation can generally be judged as "satisfactory" if NSE and RSR values are greater than 0.50 and 0.70, respectively. However, Figure 11 indicates R^2, NSE, and RSR values of 0.99, -35.25, and 6.02, respectively. Although the inverse linear relationship and misleading 0.99 R^2 value underscores the problematic concerns detailed in Legates and McCabe (1999), the NSE and RSR values of -35.25 and 6.02 indicate poor agreement of simulated to observed runoff data.

The fly ash composting pad material was observed to slough off of the pad surface from runoff and various machinery operations involved with compost windrow construction, sampling, and removal throughout 2002-2004. Consequently, loose fly ash granules moved downslope from surface runoff and accumulated in the upper margins of the 1:1 and 1:0.5 VFS buffer plots. This could have resulted in an increase of fly ash in the VFS buffers, providing a greater amount of potentially water-absorbent substrate to interact with runoff and further reduce these losses. Punjab Agriculture University researchers reported the application of fly ash as a soil amendment was found to increase the available water content of loamy sand soil by 120 percent and of sandy soil by 67 percent (PAU 1993). While this change in runoff reduction did not occur in the 1:0 (control) plots where fly ash granules also moved downslope, possibly the fly ash was functioning as a soil amendment in the VFS buffer soil, resulting in substantially greater water absorbency and runoff volume reduction. In contrast, the 1:0 control plots consisted of heavily-compacted fly ash of approximately 30.48 cm (12 in) in depth. This compacted structure may have minimized potential fly ash surface area contact to the runoff water volume. Moreover, since the VFS buffer areas also determine how the WCVFS model calculates precipitation and runoff inputs, this may have contributed to the overpredicted runoff volumes in the relatively smaller-area 1:0.5 VFS buffers.

Since 5-10 years may be required to modify soil conditions and infiltration rates in a new VFS buffer system (Richard Schultz per comm.), this could have contributed to the variability of runoff losses in the observed data used in this study. Dosskey *et al*. (2007) also found that the most change in VFS buffers occurred within three growing seasons after establishment, and infiltration characteristics accounted for most of that change.

Conclusions

This research calibrated and validated a hydrologic model for predicting runoff volume losses from a windrow composting site with VFS buffers. The site also included a composting pad surface constructed of fly ash obtained from a local coal-fired power generating station. Observed runoff and physical attribute data from six rainfall events during 2002-2004 at a central Iowa windrow composting research site were used in the model evaluation. Calibration simulations indicated good agreement of simulated runoff data to observed data for all 1:1, 1:0.5, and 1:0 (no-buffer control) VFS buffer treatments. The 1:0 (control) treatment plots also indicated good data agreement for all calibration and validation simulations. However, validation simulations resulted in overpredictions for the 1:1 and 1:0.5 VFS buffer runoff volumes that were most significant in the 2004 late rainfall events period (LE). Results from this initial study with limited data indicated that alternatives to soil data-derived VFS buffer surface infiltration and runoff functions should be considered to potentially improve model prediction accuracy. These results and other research findings suggest that the fly ash composting pad material and age of the site may have contributed to the overpredicted 1:1 and 1:0.5 VFS buffer runoff validation simulation results. More windrow composting and VFS buffer field and laboratory research is needed to more clearly understand the hydrology of these sites. With more field research results, additional observed data will be available to calibrate and validate a more accurate hydrologic model for improving runoff prediction for windrow composting sites with VFS buffers.

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Table 1. Weather data file example for rainfall event 7-3-04E4LEC for WCVFS hydrologic model calibration simulations for the windrow composting/VFS buffer research site at the ISU Dairy Teaching Farm, Ames, central Iowa, USA.

t	year	month	day	Tmax	Tmin	precip	dewpoint	potevt	dailyevap	evapcoeff
1	2004	6	23	79.7	58.0	0	65	0.285	0.31	0.78
2	2004	6	24	60.9	48.4	0	61.3	0.098	0.24	0.78
3	2004	6	25	72.1	42.7	0	64.4	0.247	0.16	0.78
4	2004	6	26	76.5	49.3	0	61.1	0.248	0.25	0.78
5	2004	6	27	74	57.1	0	63.9	0.128	0.29	0.78
6	2004	6	28	75	51.9	0	58.2	0.245	0.18	0.78
7	2004	6	29	79.1	53.1	0	57.9	0.256	0.29	0.78
8	2004	6	30	80	54.0	0	62	0.265	0.23	0.78
9	2004	7	1	85.1	60.9	0	65.5	0.258	0.38	0.78
10	2004	7	2	78.4	67.3	0	63.2	0.11	0.28	0.78
11	2004	7	3	73	64.6	1.8	63.7	0.064	0.21	0.78
12	2004	7	4	83.2	62.8	0	71.5	0.235	0.14	0.78

Table 2. Soils input parameter table example (with soil type selected in black) for the WCVFS hydrologic modeling program in ModelMaker4 for accessing soil-related data.

Soil_Type	--- Not Used ---	water_table	top_density	mid_density	bot_density	sub_density	wilt_point_top	wilt_point_mid	wilt_point_bot	wilt_point_sub	AWC_top	AWC_mid	AWC_bot
65	Otley A	0	1.30	1.34	1.38	1.42	0.174	0.196	0.210	0.181	0.176	0.189	0.183
66	Otley B	0	0.00	0.00	0.00	0.00	14.279	16.843	14.738	10.980	0.00	0.00	0.00
67	Primghar A	0	0.00	0.00	0.00	0.00	15.554	13.861	10.123	10.610	0.00	0.00	0.00
68	Primghar B	0	0.00	0.00	0.00	0.00	17.136	14.915	10.967	10.611	0.00	0.00	0.00
69	Readlyn A	0	0.00	0.00	0.00	0.00	10.133	10.295	9.345	5.900	0.00	0.00	0.00
70	Readlyn B	0	0.00	0.00	0.00	0.00	11.900	12.591	10.743	9.503	0.00	0.00	0.00
71	Sac A	0	1.25	1.25	1.49	1.62	0.212	0.187	0.190	0.227	0.181	0.213	0.145
72	Sac B	0	1.26	1.34	1.55	1.66	0.210	0.187	0.186	0.207	0.149	0.118	0.095
73	Sac C	0	1.24	1.25	1.53	1.63	0.190	0.168	0.206	0.215	0.164	0.197	0.105
74	Sac D	0	1.29	1.29	1.61	1.75	0.216	0.190	0.185	0.212	0.146	0.133	0.080
75	Salix	0	1.32	1.30	1.20	1.31	0.162	0.186	0.121	0.085	0.156	0.219	0.187
76	Sarpy	0	0.00	0.00	0.00	0.00	4.475	3.900	5.907	7.000	0.000	0.000	0.000
77	Saude	0	1.39	1.47	1.60	1.65	0.124	0.095	0.059	0.017	0.155	0.139	0.069
78	Sharpsburg A	0	1.29	1.26	1.31	1.34	0.173	0.199	0.209	0.202	0.183	0.178	0.207
79	Sharpsburg B	0	1.26	1.31	1.35	1.33	0.180	0.231	0.227	0.202	0.142	0.152	0.174
80	Sharpsburg C	0	0.00	0.00	0.00	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000
81	Sparta	0	0.00	0.00	0.00	0.00	3.100	1.911	5.300	1.100	0.000	0.000	0.000
82	Spillville	0	1.22	1.31	1.30	1.47	0.183	0.161	0.122	0.109	0.185	0.190	0.240
83	Storden A	0	1.42	1.50	1.66	1.71	0.141	0.156	0.192	0.195	0.147	0.127	0.127
84	Storden B	0	0.00	0.00	0.00	0.00	10.298	11.290	11.356	11.200	0.000	0.000	0.000
85	Storden C	0	0.00	0.00	0.00	0.00	9.700	10.167	11.128	11.432	0.000	0.000	0.000
86	Taintor	0	0.00	0.00	0.00	0.00	18.950	18.659	15.918	13.541	29.350	28.254	26.843
87	Taintor B	0	0.00	0.00	0.00	0.00	17.318	18.166	16.084	12.778	0.000	0.000	0.000
88	Tama A	0	1.31	1.38	1.41	1.60	0.174	0.210	0.188	0.159	0.190	0.177	0.206
89	Tama B	0	1.23	1.39	1.42	1.46	0.125	0.119	0.179	0.165	0.126	0.176	0.162
90	Tama C	0	0.00	0.00	0.00	0.00	13.600	13.136	12.627	11.262	0.000	0.000	0.000
91	Vesser	0	1.34	1.42	1.48	1.57	0.177	0.171	0.243	0.206	0.193	0.208	0.150
92	Wadena A	0	1.23	1.31	1.58	1.70	0.138	0.153	0.137	0.050	0.202	0.172	0.115
93	Wadena B	0	1.34	1.38	1.61	1.68	0.130	0.140	0.100	0.024	0.213	0.168	0.045
94	Webster A	0	1.20	1.35	1.53	1.65	0.255	0.223	0.126	0.136	0.180	0.132	0.109
95	Webster B	0	1.23	1.35	1.52	1.63	0.273	0.203	0.142	0.092	0.161	0.160	0.138
96	Wiota A	0	1.38	1.33	1.40	1.66	0.148	0.161	0.239	0.040	0.192	0.193	0.141
97	Wiota B	0	1.26	1.38	1.47	1.71	0.141	0.178	0.225	0.051	0.247	0.194	0.139
98	Zook A	4	1.29	1.36	1.44	1.45	0.265	0.248	0.302	0.261	0.109	0.125	0.096
99	Zook B	4	1.39	1.42	1.48	1.51	0.225	0.277	0.259	0.242	0.157	0.113	0.141
100	Zook C	4	1.30	1.34	1.42	1.38	0.264	0.258	0.272	0.261	0.119	0.118	0.111

Table 3. Vegetation input parameter table example (with vegetation type selected in black) for the WCVFS hydrologic modeling program in ModelMaker4 for accessing vegetation-related data.

VTA_Veg	--- Not Used ---	N_Uptake_HighN	N_Uptake_LowN	P_Uptake_HighP	P_Uptake_LowP	Manning_n	retardance_class	spacing
1	Reeds Canary Grass	350	185	40	20	0.080	1	0.0575
2	Reeds Canary Grass	350	185	40	20	0.080	1	0.0725
3	Reeds Canary Grass	320	170	36	18	0.065	2	0.0575
4	Reeds Canary Grass	320	170	36	18	0.065	2	0.0725
5	Reeds Canary Grass	280	150	32	15	0.050	3	0.0575
6	Reeds Canary Grass	280	150	32	15	0.050	3	0.0725
7	Bromegrass	250	135	30	12	0.065	2	0.0650
8	Bromegrass	250	135	30	12	0.065	2	0.0475
9	Bromegrass	225	120	26	10	0.050	3	0.0650
10	Bromegrass	225	120	26	10	0.050	3	0.0475
11	OrchardGrass	200	110	24	10	0.040	3	0.0450
12	OrchardGrass	200	110	24	10	0.040	3	0.0550
13	OrchardGrass	180	100	20	8	0.040	4	0.0650
14	OrchardGrass	180	100	20	8	0.040	4	0.0725

Table 4. Rainfall events, input parameters, output data, and statistical analysis results for the WCVFS hydrologic modeling calibration and validation simulations. Event dates are followed by event numbers (E1-E6), event periods (early events [EE] and late events [LE]), model run calibrations (Cal) and validations (Val), compost pile and pad Curve Numbers (CN), seasonal water table depth (WT), observed (Obs) and simulated (Sim) VFS buffer treatment runoff volumes for 1:0 (control), 1:1, and 1:0.5 plot areas, and standard regression (R^2), Nash-Sutcliffe Efficiency (NSE), and the root mean square error (RMSE) observations standard deviation ratio (RSR) statistical values.

Input parameters and observed runoff volumes

Event	Event number	Event period	Model run	Pile (CN)	Pad (CN)	WT (ft)	1:0 obs (L)	1:1 obs (L)	1:0.5 obs (L)
8-5-02	E1	EE	Cal	93	89	2.7	1406	144	481
6-25-03	E2	EE	Cal	87	80	3.5	3625	18	581
7-5-03	E3	EE	Val	90	89	3.1	3661	436	758
7-3-04	E4	LE	Cal	93	66	2.7	271	1.4	1.0
8-26-04	E5	LE	Cal	95	78	1.5	414	10	8.0
9-6-04	E6	LE	Val	94	78	1.5	744	3.9	2.3

Simulated runoff volumes and statistical results

Event	Event number	Event period	Model run	1:0 sim (L)	1:1 sim (L)	1:0.5 sim (L)	R^2 stat	NSE stat	RSR stat
8-5-02	E1	EE	Cal	1424	148	465	0.99	0.99	0.05
6-25-03	E2	EE	Cal	3588	72	705	0.99	0.99	0.05
7-5-03	E3	EE	Val	3501	296	2471	0.65	0.53	0.69
7-3-04	E4	LE	Cal	256	14	9.9	0.99	0.98	0.13
8-26-04	E5	LE	Cal	390	8.0	48	0.99	0.98	0.13
9-6-04	E6	LE	Val	964	2674	2470	0.98	-35.25	6.02

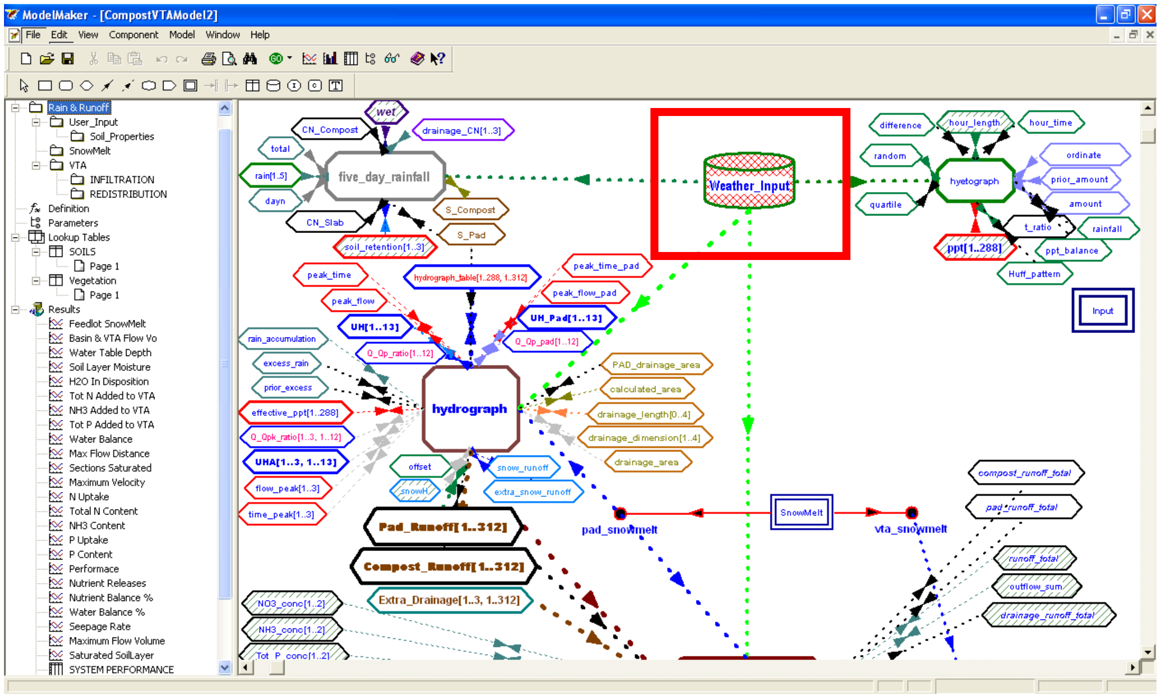

Figure 1. Main user input screen of WCVFS hydrologic modeling program in ModelMaker4. Double-clicking on the red, thick rectangle outlining "Weather Input" cross-hatched user input icon accesses selected weather files and initiates the data input and simulation functions.

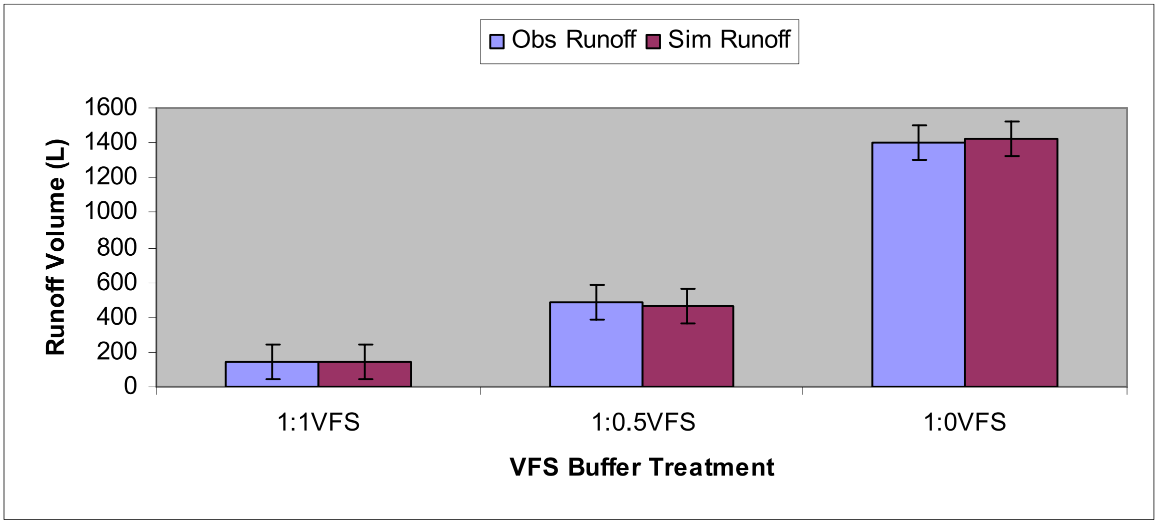

Figure 2. Observed versus simulated runoff volumes (L) from 1:1, 1:0.5, and 1:0 VFS buffer treatments for event 8-5-02E1EEC calibration simulation using the WCVFS hydrologic modeling program.

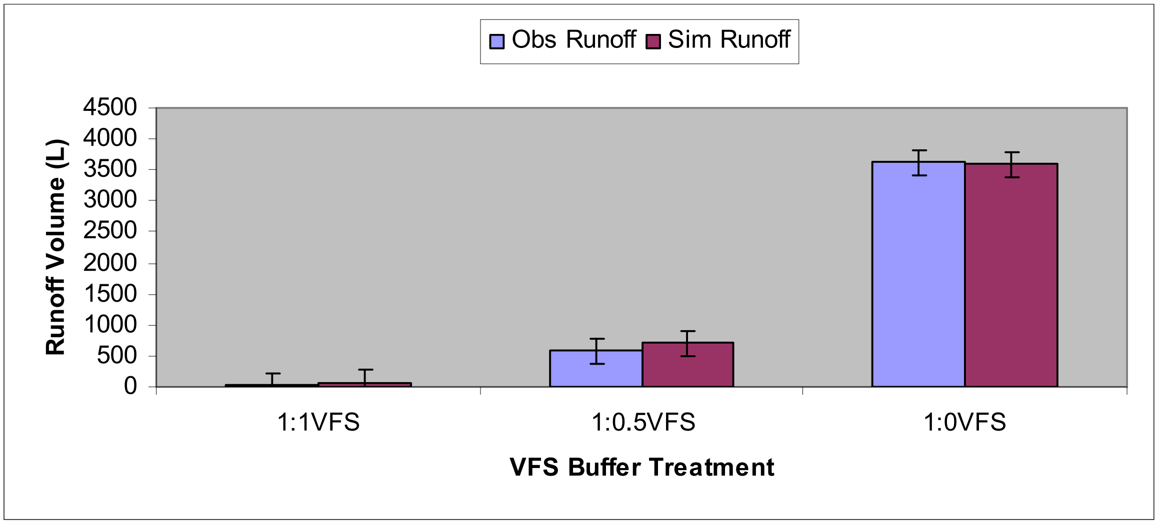

Figure 3. Observed versus simulated runoff volumes (L) from 1:1, 1:0.5, and 1:0 VFS buffer treatments for event 6-25-03E2EEC calibration simulation using the WCVFS hydrologic modeling program.

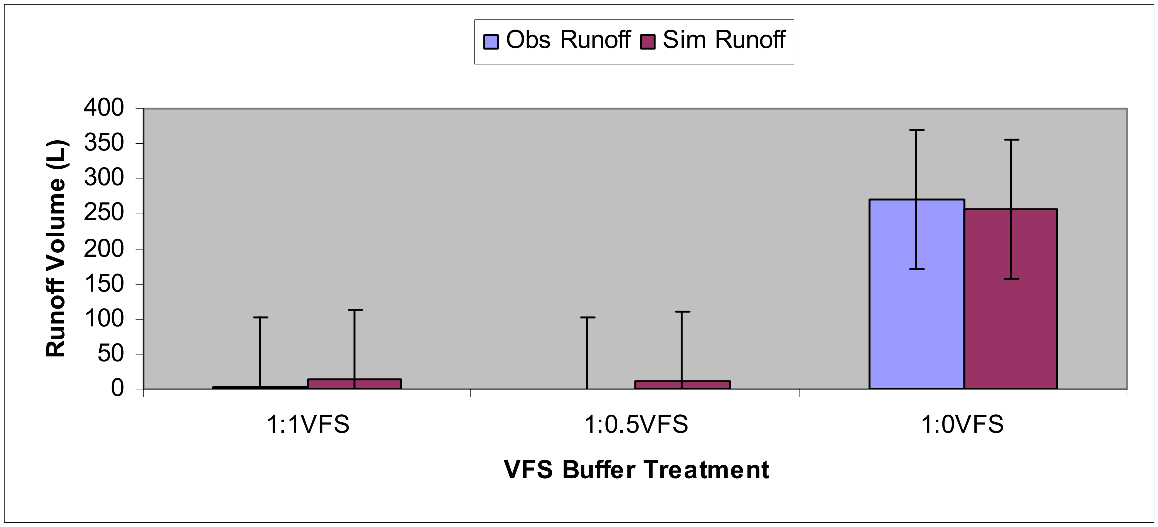

Figure 4. Observed versus simulated runoff volumes (L) from 1:1, 1:0.5, and 1:0 VFS buffer treatments for event 7-3-04E4LEC calibration simulation using the WCVFS hydrologic modeling program.

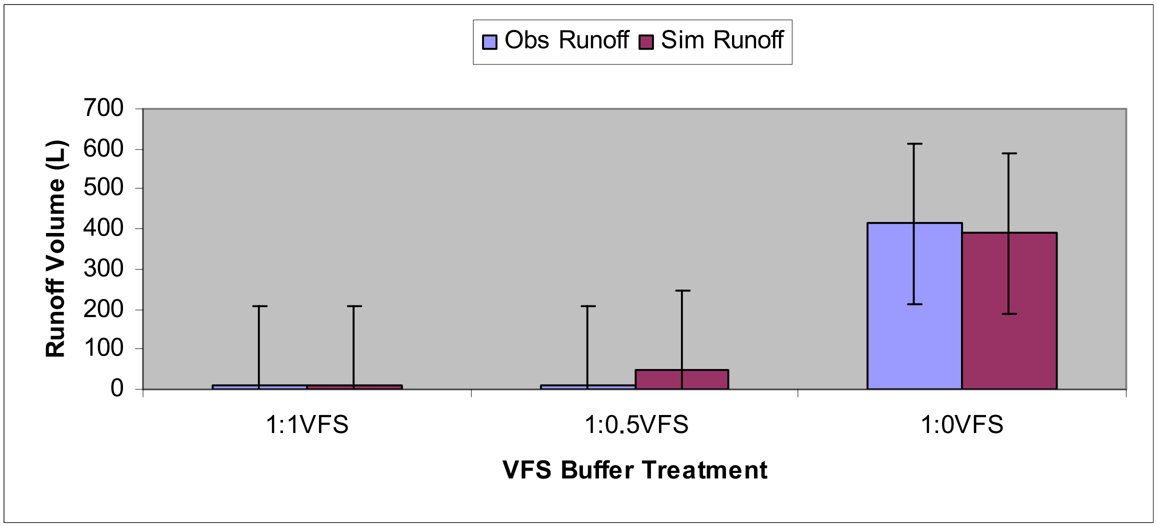

Figure 5. Observed versus simulated runoff volumes (L) from 1:1, 1:0.5, and 1:0 VFS buffer treatments for event 8-26-04E5LEC calibration simulation using the WCVFS hydrologic modeling program.

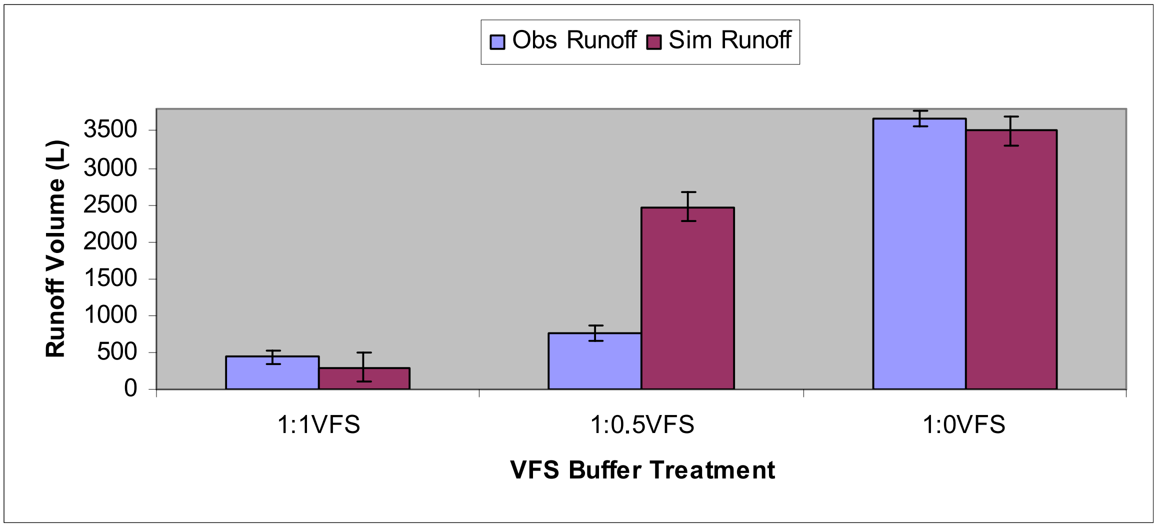

Figure 6. Observed versus simulated runoff volumes (L) from 1:1, 1:0.5, and 1:0 VFS buffer treatments for event 7-5-03E3EEV validation simulation using the WCVFS hydrologic modeling program.

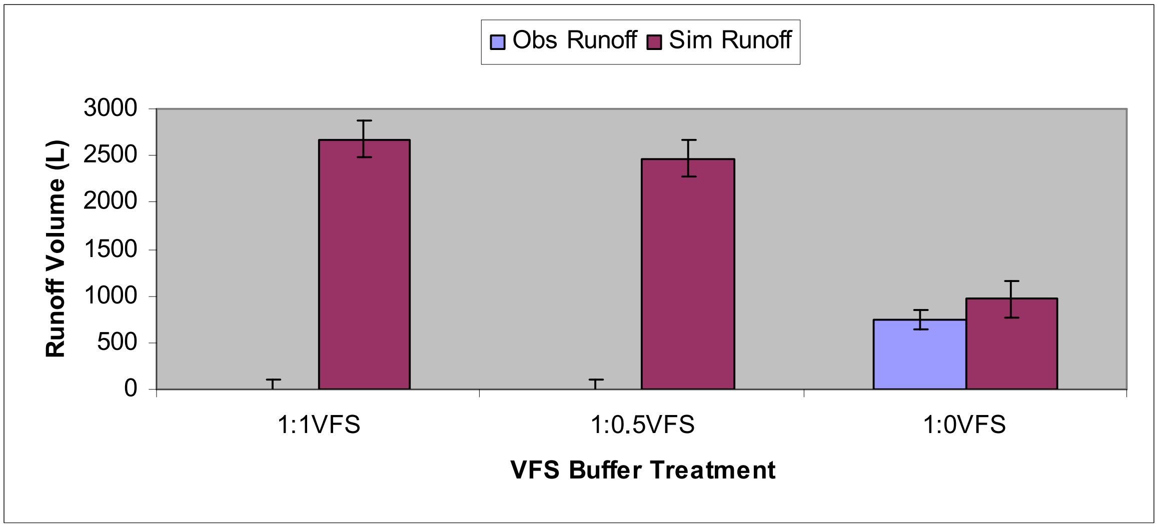

Figure 7. Observed versus simulated runoff volumes (L) from 1:1, 1:0.5, and 1:0 VFS buffer treatments for event 9-6-04E6LEV validation simulation using the WCVFS hydrologic modeling program.

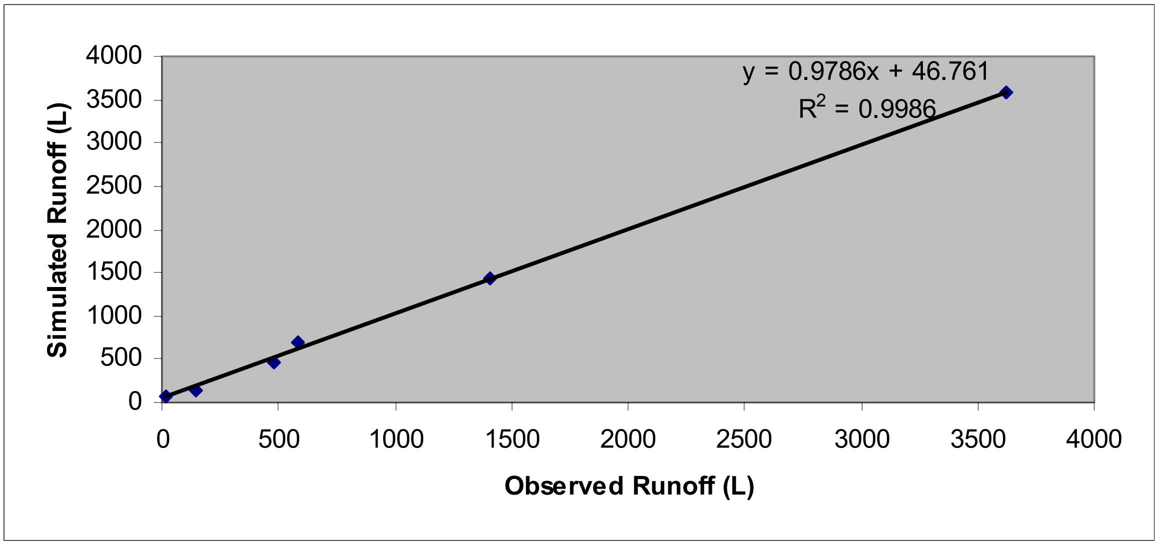

Figure 8. Standard regression (R^2 = 0.99) for observed versus simulated runoff volumes (L) from 1:1, 1:0.5, and 1:0 VFS buffer treatments for events 8-5-02E1EEC and 6-25-03E3EEC calibration simulations using the WCVFS hydrologic modeling program. NSE and RSR statistical values = 0.99 and 0.05, respectively.

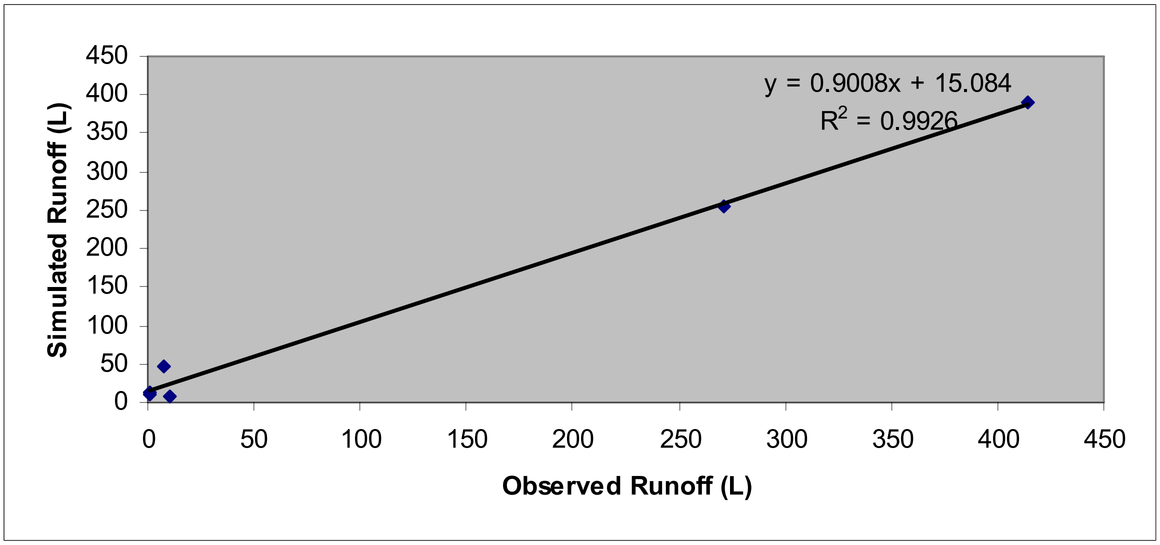

Figure 9. Standard regression (R^2 = 0.99) for observed versus simulated runoff volumes (L) from 1:1, 1:0.5, and 1:0 VFS buffer treatments for events 7-3-04E4LEC and 8-26-04E5LEC calibration simulations using the WCVFS hydrologic modeling program. NSE and RSR statistical values = 0.98 and 0.13, respectively.

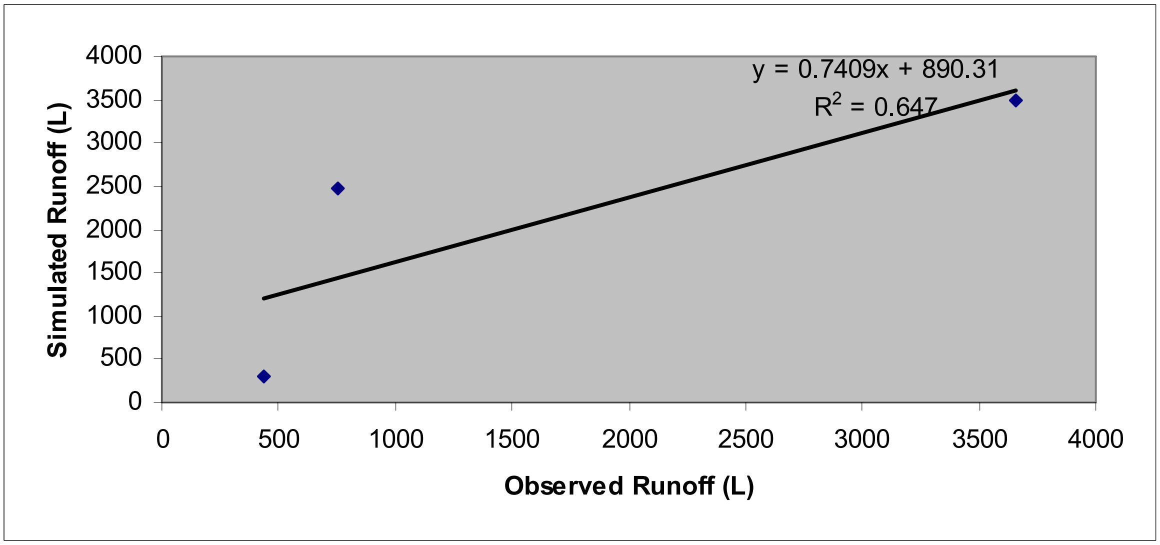

Figure 10. Standard regression (R^2 = 0.65) for observed versus simulated runoff volumes (L) from 1:1, 1:0.5, and 1:0 VFS buffer treatments for event 7-5-03E3EEV validation simulation using the WCVFS hydrologic modeling program. NSE and RSR statistical values = 0.53 and 0.69, respectively.

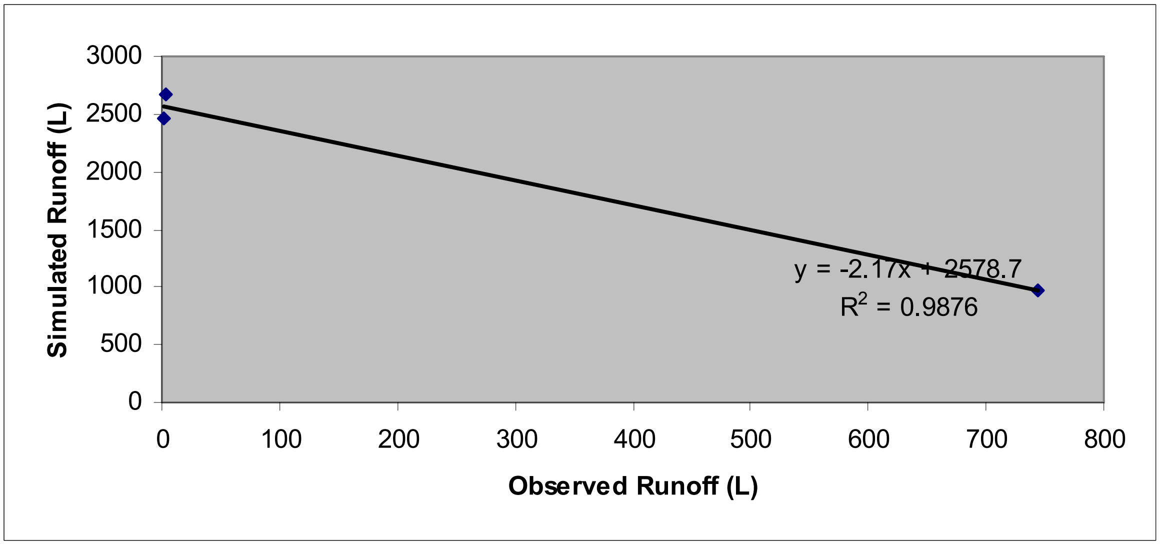

Figure 11. Standard regression (R^2 = 0.99) for observed versus simulated runoff volumes (L) from 1:1, 1:0.5, and 1:0 VFS buffer treatments for event 9-6-04E6LEV validation simulation using the WCVFS hydrologic modeling program. Note inverse relationship and misleading R^2 value, and low NSE and RSR statistical values of -35.25 and 6.02, respectively, indicating poor agreement of simulated results to observed runoff data.

CHAPTER 6: GENERAL CONCLUSIONS

General Discussion

Surface runoff containing nonpoint source (NPS) pollution is a serious problem for the nation's water resources. The most recent national water quality inventory shows that, as of 2000, 39 percent of assessed stream miles, 45 percent of assessed lake acres, and 51 percent of assessed estuary acres are impaired. (EPA, 2003). State inventories of water quality indicate that production agriculture activities impact 18 percent of the total river and stream miles assessed and 48 percent of impaired rivers and streams (EPA, 2002). Livestock grazing can significantly affect the soil-water environment (Schepers and Francis, 1982; Owens et al., 1989; Nelson et al., 1996; Krzic et al., 2006). Grazed pastures can contribute phosphorus (P) to surface waters (Downing et al., 2000), and have higher P losses than non-grazed pastures (Gillingham and Thorrold, 2000). Various studies have indicated that N and P losses from continuous grazing pastures are generally higher than rotational grazing and non-grazed pastures (Ritter, 1988; Mathews et al., 1994).

Although livestock grazing activities can adversely impact the complex soil-water environment, Sharpley and Syers (1976) determined that P transport due to grazing animals was significantly less than P losses from fertilizer addition. Nash et al. (2000) found that cattle grazing did not result in large stores of available P compared to P fertilization. Mathews et al. (1994) also found the grazing method of well-managed pastures may have little effect on short-term soil nutrient distribution, especially when grazing occurs during months when temperatures are high. While grazing management practices can have variable effects on runoff, erosion, and nutrient losses from pasture systems, vegetative characteristics of different forage species also can influence the surface hydrology of these landscapes. Self-Davis et al. (2003) researched various forage plant species and cover effects from small vegetated plots and determined that tall fescue (*Festuca arundinacea* Schreber.) significantly reduced runoff and increased infiltration. Several researchers also have shown the inclusion of warm-season grass types into a rotational grazing sequence cannot only improve vegetation quality and grazing efficiency (Mitchell et al., 1998; Moore et al., 2004; Roberts and Kallenbach, 2006), but may reduce runoff, sediment, and nutrient losses in areas with slopes less than 4 percent (Broadmeadow and Nisbet, 2004).

Windrow composting consists of placing manure and other raw materials in long narrow piles or windrows which are agitated or turned on a regular basis (Rynk et al., 1992). Studies have shown that composted manure is less hazardous to the environment (Eghball and Power, 1999; Vervoort et al., 1998) and much of the mineral N is converted to more stable organic forms (Rynk et al., 1992). Compost also has been shown to significantly reduce P in runoff from road construction sites (Jurries 2003) and nitrate (NO_3-N) leaching relative to conventional fertilizers (Maynard, 1993). However, one of the disadvantages of composting is nutrient loss during the composting process, which can occur through leaching, runoff, and volatilization (Christensen, 1983, 1984; Richard and Chadsey, 1994; Eghball et al., 1997; Tiquia et al., 2000). Mass balance analysis results of a composting site indicated 20-60 percent losses of N, P, and potassium (K) during composting processes (Tiquia et al., 2002), of which the most significant losses were runoff and leachate (Garrison et al., 2001). Seymour and Bourdon (2003) reported concentrations of NO_3-N, ortho-P (PO_4-P), and K were highest in leachate compared to runoff samples from compost windrows under natural rainfall conditions. Wilson et al. (2004) reported that approximately 68 percent of rainfall incident on saturated compost windrows from both natural and simulated rainfall events resulted in runoff.

Vegetative filter strip (VFS) buffers are bands of vegetation located downslope of cropland or other potential pollutant source areas. These buffer strips provide erosion control and filter nutrients, pesticides, sediment, and other pollutants from agricultural runoff by reducing the sediment carrier and through interception-adsorption, infiltration, and degradation of pollutants dissolved in water (Dillaha et al., 1989). VFS buffers also have been suggested as a best management practice (BMP) that has been shown to reduce sediment and nutrient losses in a range of agricultural settings, including crop fields and feedlots (Magette et al., 1989; Patty et al., 1997). The effectiveness of VFS buffers in controlling pollutants from cropland also has been assessed by several researchers (Dillaha et al., 1985; Mickelson and Baker, 1993; Lee, 2000). These researchers found that VFS buffers have potential for significantly improving the water quality of runoff. However, the effectiveness of VFS buffers depends on many factors, such as vegetation species, soil type, soil texture, type of contaminant, slope of the runoff area, activities on the runoff area (i.e. tillage), and field condition (Dillaha et al., 1989; Arora et al., 1996; Schmitt et al., 1999; Lee, 2000; Abu-Zreig et al., 2003; Goel et al., 2004; Petersen and Vondracek, 2006).

Hydrologic models have been used for over 30 years to simulate sediment and nutrient transport in surface runoff through VFS buffers (Tollner, et al. 1976; Delgado, et al. 1992; Srivastava, et al. 1998). However, few reports exist regarding hydrologic models for predicting runoff losses from windrow composting sites. Governo (2001) developed a spreadsheet-based computer program to assist in the design phase of windrow composting facilities, but did not include a hydrologic modeling component. Tollner and Das (2004) evaluated hydrologic models that applied the NRCS Curve Number method for predicting runoff from a yard waste windrow composting site. Although this research effort described a hydrologic modeling approach for windrow composting sites, it does not include a runoff modeling function for VFS buffers. Wilson et al. (2004) reported that approximately 68 percent of rainfall incident on saturated compost windrows from both natural and simulated rainfall events resulted in runoff, using the 0.68 value as a runoff coefficient.

Results from the Chapter 3 grazing study for 2001 and 2002 show no significant differences ($p < 0.10$) in average losses of RO, TS, NO_3-N, PO_4-P, and TP among the nine treatments. The 2003 results also show no significant differences ($p < 0.10$) in losses of RO, TS, PO_4-P, and TP. However, the 2003 results indicate significantly high ($p < 0.01$) losses of NO_3-N from "10:1ng" treatments and, while not significant, may indicate a tendency towards elevated losses to some "ng" treatments from the "con" treatments in 2001 and 2002. Although there were no significant differences ($p < 0.10$) among treatment combinations for the 2001, 2002, and 2003 average TS and nutrient concentration results, the relatively higher runoff volume for the "10:1ng" treatment combination complements the significantly higher NO_3-N losses with runoff.

Overall, the runoff analysis results indicate grazing management practice did not significantly affect runoff. These results also suggest the relatively higher 2003 event precipitation depth, antecedent moisture conditions, and the dense cool-season smooth brome may have contributed to the potential shift of elevated losses to the non-grazed "ng" control treatments. Concentrated flow conditions through the paddocks and VFS buffers also may have contributed to elevated runoff and NO_3-N losses since the Rhodes research site is located in the Southern Iowa Drift Plain Landform, a generally high-relief landscape that is characterized by an extensive drainage network of deeply-incised rills, ravines, and stream channels (Prior, 1991). Research comparing smooth brome to warm-season species, like switchgrass and big bluestem, shows that warm-season types are more effective VFS buffer vegetation for reducing RO, TS, and nutrient losses. However, the Rhodes site includes slopes up to 15 percent, and the sod-forming smooth brome is recommended for areas with slopes greater than 10 percent (SCS, 1979).

Although warm-season grasses could be incorporated into a rotational grazing management program to improve grazing efficiency and reduce RO and contaminant losses, Vinton and Goergen (2006) suggested that smooth brome may have a competitive advantage over warm-season switchgrass on higher-N soils. Consequently, the increased N deposition associated with livestock grazing and fertilizer application could result in an even greater smooth brome competitive advantage, requiring special vegetation management strategies such as prescribed burning. By locating the warm-season grass paddocks low in the landscape adjacent to the VFS buffers and smooth brome on the upslope areas, prescribed burning could be effectively applied to the warm-season grass areas to reduce the aggressive smooth brome encroachment. Current research indicates that annually repeated mid- to late spring (May to early June) prescribed burning reduces smooth brome tiller numbers, favoring growth and development of warm-season grass species (USGS, 2006).

The research conducted for the Chapter 4 windrow composting/VFS buffer study quantifies the effects of windrow composting practices and vegetative filter strip (VFS) buffers on losses of runoff (RO), runoff percent of rainfall (RO%), total solids (TS), nitrate-nitrogen (NO_3-N), ortho-phosphorus (PO_4-P), and total-phosphorus (TP) during natural rainfall events. Runoff data from six events were collected during June-July (early season) and August-September (late season) 60-day composting periods from 2002-2004 at an Iowa State University research farm near Ames, central Iowa, USA. Results from the study indicate significantly higher levels ($p < 0.05$) of RO, RO%, TS, NO_3-N, PO_4-P, and TP from the 1:0 control plots compared to the 1:1 and 1:0.5 plots. Results also show the 1:1 and 1:0.5 VFS buffer treatments were not significantly different ($p < 0.05$). Average runoff loss reductions from the 1:1 and 1:0.5 plots were 98 and 93 percent, respectively, compared to the 1:0 control plots. These results reflect the effectiveness of VFS buffers for reducing runoff and contaminant losses from a windrow composting site.

Compost nutrient mass balance analysis results indicate 26-41 percent of PO_4-P was lost from the compost windrows during the 2004 composting periods. However, only 0.1-0.4 percent of PO_4-P was lost to runoff from the 1:0 control plots. We hypothesize the significantly lower PO_4-P losses in runoff may be attributed to potential chemical and physical effects of the fly ash composting pad material. Political and social interests are increasingly directed towards adopting more environmentally responsible strategies that reclaim or recycle certain waste materials and protect natural resources. Consequently, future research efforts could include a comparison of fly ash to other composting pad surface materials to more thoroughly evaluate the efficacy of this industrial by-product in reducing offsite runoff and contaminant transport from windrow composting facilities.

The Chapter 5 study calibrated and validated a hydrologic model for predicting runoff volume losses from a windrow composting site. The site included vegetative filter strip (VFS) buffers and a fly ash composting pad surface. Observed runoff and physical attribute data from six rainfall events during 2002-2004 at a central Iowa windrow composting research site were used in the model evaluation. Calibration simulations indicated good agreement of simulated runoff data to observed data. The 1:0 (control) treatment plots also indicated good data agreement for all calibration and validation simulations. However, validation simulations resulted in overpredictions of 1:1 and 1:0.5 VFS buffer runoff volumes that were most dramatic in the 2004 final rainfall events period (LE). Results from this initial study with limited data indicated that alternatives to soil-derived VFS buffer surface infiltration and runoff functions should be considered to potentially improve model prediction accuracy. These results and other research findings suggest that possibly the fly ash compost pad material and age of the site may be contributing to the overpredicted 1:1 and 1:0.5 VFS buffer runoff validation simulation results. More windrow composting and VFS buffer field and laboratory research is needed to more clearly understand the hydrology of these sites. Other infiltration and runoff functions should be considered to potentially improve model prediction accuracy. With more field research results, additional observed data will be available to calibrate and validate more accurate hydrologic modeling simulations for improving runoff prediction for windrow composting sites with VFS buffers.

Suggestions for Future Research

While existing investigations have provided knowledge about the effectiveness of windrow composting and VFS buffers in reducing sediment and nutrient losses in runoff, further study is necessary to fully understand how these BMPs function to enhance their environmental benefit. Suggestions for future work include:

1. More comprehensive comparisons of fly ash to other windrow composting pad surface materials to more clearly understand infiltration and runoff characteristics.
2. Studies comparing runoff volume, sediment, and nutrient transport from plots with and without compost windrows and between newly-established and older sites.
3. Quantitative studies of VFS buffer vegetation type and tiller density and their effects on runoff volume and contaminant transport.
4. Obtaining additional windrow composting/VFS buffer site field and laboratory data for calibrating and validating a more accurate hydrologic model to improve runoff prediction.

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APPENDIX A

RAW DATA FOR GRAZING SITE SEDIMENT AND NUTRIENT CONCENTRATIONS AND TOTAL LOSSES WITH RUNOFF

Table A1. Raw data on runoff depth and concentrations of sediment, NO_3-N, PO_4-P, and total-P from grazing and VFS buffer treatments for rainfall event 7-19-01E1 at the ISU Rhodes Research Farm site, central Iowa, USA.

ID	Sample	Plot	Buffer ratio	Grazing practice	Runoff mm	Solids g/kg	NO_3-N mg/L	PO_4-P mg/L	Total-P mg/L
R01E1	1	2	10:1	con	0.34	0.11	0.36	0.45	1.24
R01E1	2	2	NB	con	0.29	0.10	0.32	0.30	0.82
R01E1	3	2	5:1	con	0.65	0.38	0.29	0.33	1.06
R01E1	4	2	NB	rot	0.50	0.32	1.22	0.27	0.64
R01E1	5	2	5:1	rot	0.29	0.11	0.34	0.40	0.92
R01E1	6	2	10:1	rot	0.75	0.10	0.30	1.14	1.84
R01E1	7	2	5:1	ng	0.45	0.08	0.12	0.40	0.84
R01E1	8	2	10:1	ng	0.57	0.05	0.40	0.43	0.89
R01E1	9	2	NB	ng	0.35	0.11	0.01	0.59	1.06
R01E1	10	1	5:1	ng	0.72	0.26	0.03	0.49	1.14
R01E1	11	1	10:1	ng	2.57	0.09	0.27	0.11	0.42
R01E1	12	1	NB	ng	0.64	0.42	0.83	0.24	0.76
R01E1	13	1	5:1	con	0.08	1.60	0.04	10.61	11.81
R01E1	14	1	10:1	con	0.09				
R01E1	15	1	NB	con	0.09	1.71	0.31	9.13	10.63
R01E1	16	1	10:1	rot	0.28	0.71	2.21	0.62	1.72
R01E1	17	1	5:1	rot	0.05	1.32	0.00	2.55	3.29
R01E1	18	1	NB	rot	0.11	1.56	0.47	0.70	1.16
R01E1	19	3	NB	rot	0.42	0.73	0.29	0.56	0.79
R01E1	20	3	5:1	rot	0.40	0.87	0.05	0.62	0.99
R01E1	21	3	10:1	rot	0.14	0.70	0.35	0.31	0.74
R01E1	22	3	5:1	con	0.46	0.75	0.26	0.20	0.49
R01E1	23	3	10:1	con	0.30	0.42	0.24	0.19	0.62
R01E1	24	3	NB	con	0.39	0.39	0.45	0.28	1.06
R01E1	25	3	10:1	ng	0.43	0.10	1.02	0.73	1.42
R01E1	26	3	NB	ng	0.40	0.08	0.25	0.55	0.96
R01E1	27	3	5:1	ng	0.34	0.54	0.00	0.80	1.46

Table A2. Raw data on runoff depth and concentrations of sediment, NO_3-N, PO_4-P, and total-P from grazing and VFS buffer treatments for rainfall event 8-3-01E2 at the ISU Rhodes Research Farm site, central Iowa, USA.

ID	Sample	Plot	Buffer ratio	Grazing practice	Runoff mm	Solids g/kg	NO_3-N mg/L	PO_4-P mg/L	Total-P mg/L
R01E2	1	2	10:1	con	0.65	0.39	0.04	0.51	0.63
R01E2	2	2	NB	con	0.39	0.43	0.66	0.90	1.14
R01E2	3	2	5:1	con	0.38	0.39	0.06	0.83	0.93
R01E2	4	2	NB	rot	0.31	0.05	0.00	0.29	0.66
R01E2	5	2	5:1	rot	0.34	0.03	0.21	0.10	0.39
R01E2	6	2	10:1	rot	0.06	0.12	0.22	0.59	0.87
R01E2	7	2	5:1	ng	0.20	0.24	0.14	0.27	0.65
R01E2	8	2	10:1	ng	0.25	0.20	0.75	0.58	0.94
R01E2	9	2	NB	ng	0.13	0.60	0.22	0.38	0.75
R01E2	10	1	5:1	ng	0.11	1.00	0.13	0.22	0.72
R01E2	11	1	10:1	ng	2.12	0.58	0.24	0.19	0.54
R01E2	12	1	NB	ng	0.67	0.54	0.00	0.46	1.09
R01E2	13	1	5:1	con	0.08	1.16	0.00	3.64	11.22
R01E2	14	1	10:1	con	0.33	0.42	1.54	0.56	0.93
R01E2	15	1	NB	con	1.03	0.43	2.86	0.71	1.07
R01E2	16	1	10:1	rot	1.84	0.18	2.46	0.43	0.68
R01E2	17	1	5:1	rot	1.09	0.12	1.08	0.27	0.52
R01E2	18	1	NB	rot	0.26	0.53	0.66	0.41	1.11
R01E2	19	3	NB	rot	0.86	0.18	0.46	1.01	1.32
R01E2	20	3	5:1	rot	0.32	1.03	0.29	0.15	0.44
R01E2	21	3	10:1	rot	0.17	0.03	0.32	0.16	0.29
R01E2	22	3	5:1	con	0.38	0.77	0.80	0.30	0.62
R01E2	23	3	10:1	con	0.24	0.69	0.32	0.08	0.27
R01E2	24	3	NB	con	0.28	0.55	0.48	0.11	0.4
R01E2	25	3	10:1	ng	0.28	0.05	0.08	1.31	1.52
R01E2	26	3	NB	ng	0.30	0.11	0.00	1.61	0.43
R01E2	27	3	5:1	ng	0.03	0.60	0.00	1.91	2.51

Table A3. Raw data on runoff depth and concentrations of sediment, NO_3-N, PO_4-P, and total-P from grazing and VFS buffer treatments for rainfall event 9-7-01E3at the ISU Rhodes Research Farm site, central Iowa, USA.

ID	Sample	Plot	Buffer ratio	Grazing practice	Runoff mm	Solids g/kg	NO_3-N mg/L	PO_4-P mg/L	Total-P mg/L
R01E3	1	2	10:1	con	0.31	2.31	0.01	0.35	0.75
R01E3	2	2	NB	con	0.36	0.95	0.06	0.28	0.43
R01E3	3	2	5:1	con	0.09	0.77	0.17	0.28	0.62
R01E3	4	2	NB	rot	0.28	0.77	0.00	0.35	1.02
R01E3	5	2	5:1	rot	0.07	0.64	0.06	0.51	0.92
R01E3	6	2	10:1	rot	0.14	0.16	0.11	0.52	0.24
R01E3	7	2	5:1	ng	0.08	2.35	0.00	0.67	2.34
R01E3	8	2	10:1	ng	0.34	1.18	0.02	0.24	1.74
R01E3	9	2	NB	ng	0.16	0.67	0.23	0.81	1.31
R01E3	10	1	5:1	ng	0.29	1.21	0.03	0.15	0.24
R01E3	11	1	10:1	ng	1.07	0.25	0.10	0.15	0.30
R01E3	12	1	NB	ng	1.15	1.43	0.01	0.06	0.67
R01E3	13	1	5:1	con	6.21	0.27	0.41	1.04	1.35
R01E3	14	1	10:1	con	6.01	0.21	0.93	0.58	0.90
R01E3	15	1	NB	con	6.03	0.55	0.94	0.83	1.37
R01E3	16	1	10:1	rot	8.03	0.19	1.61	0.69	0.88
R01E3	17	1	5:1	rot	3.45	0.13	0.60	0.37	0.41
R01E3	18	1	NB	rot	3.5	0.99	1.06	0.30	0.55
R01E3	19	3	NB	rot	0.68	0.19	0.12	0.70	0.92
R01E3	20	3	5:1	rot	0.29	1.19	0.02	0.37	1.05
R01E3	21	3	10:1	rot	0.33	0.14	0.27	0.30	0.50
R01E3	22	3	5:1	con	0.25	1.45	0.10	0.38	1.24
R01E3	23	3	10:1	con	3.02	1.32	0.71	0.28	0.44
R01E3	24	3	NB	con	6.98	0.36	1.44	0.45	0.82
R01E3	25	3	10:1	ng	0.25	0.05	0.20	0.58	2.83
R01E3	26	3	NB	ng	0.27	1.70	1.85	1.81	3.34
R01E3	27	3	5:1	ng	0.16	0.93	1.04	2.68	3.20

Table A4. Raw data on runoff depth and concentrations of sediment, NO_3-N, PO_4-P, and total-P from grazing and VFS buffer treatments for rainfall event 10-22-01E4 at the ISU Rhodes Research Farm site, central Iowa, USA.

ID	Sample	Plot	Buffer ratio	Grazing practice	Runoff mm	Solids g/kg	NO_3-N mg/L	PO_4-P mg/L	Total-P mg/L
R01E4	1	2	10:1	con	0.00	2.63	0.00	1.61	3.33
R01E4	2	2	NB	con	0.00	0.08	0.22	0.04	0.30
R01E4	3	2	5:1	con	0.06	0.29	0.12	1.57	1.95
R01E4	4	2	NB	rot	0.09	0.14	0.18	0.87	0.93
R01E4	5	2	5:1	rot	0.00	0.12	0.43	0.90	0.90
R01E4	6	2	10:1	rot	0.06	0.11	0.40	1.00	1.04
R01E4	7	2	5:1	ng	0.08	0.92	0.00	2.30	3.20
R01E4	8	2	10:1	ng	0.06	0.42	0.50	2.01	2.08
R01E4	9	2	NB	ng		0.31	0.19	2.22	2.57
R01E4	10	1	5:1	ng	0.37	0.37	0.02	0.22	0.41
R01E4	11	1	10:1	ng	0.85	0.25	0.16	0.25	0.34
R01E4	12	1	NB	ng	1.37	0.13	0.06	0.19	1.15
R01E4	13	1	5:1	con	0.73	0.40	0.40	0.70	1.07
R01E4	14	1	10:1	con	0.00	0.29	1.25	3.19	3.16
R01E4	15	1	NB	con	0.00	0.86	0.56	1.72	2.01
R01E4	16	1	10:1	rot	3.70	0.41	0.49	0.59	1.01
R01E4	17	1	5:1	rot	2.25	0.35	0.22	0.46	0.69
R01E4	18	1	NB	rot	3.10	1.24	0.39	0.35	1.35
R01E4	19	3	NB	rot	1.60	0.13	0.24	0.66	0.67
R01E4	20	3	5:1	rot	0.21	0.68	0.04	0.57	1.23
R01E4	21	3	10:1	rot	1.24	0.10	0.53	1.01	1.02
R01E4	22	3	5:1	con	0.66	0.82	0.16	0.43	0.60
R01E4	23	3	10:1	con		0.17	0.79	0.32	0.45
R01E4	24	3	NB	con	2.48		2.46		
R01E4	25	3	10:1	ng	0.18	0.13	0.24	0.47	0.63
R01E4	26	3	NB	ng	0.70	0.33	0.03	0.33	0.84
R01E4	27	3	5:1	ng	0.53	0.46	0.05	1.80	2.07

Table A5. Raw data on runoff volume and total losses of sediment, NO_3-N, PO_4-P, and total-P from grazing and VFS buffer treatments for rainfall event 7-19-01E1 at the ISU Rhodes Research Farm site, central Iowa, USA.

ID	Sample	Plot	Buffer ratio	Grazing practice	Runoff L	Solids g	NO_3-N mg	PO_4-P mg	Total-P mg
R01E1	1	2	10:1	con	19.76	2.10	7.14	8.86	24.50
R01E1	2	2	NB	con	15.33	1.53	4.87	4.57	12.57
R01E1	3	2	5:1	con	40.80	15.49	11.88	13.53	43.25
R01E1	4	2	NB	rot	26.04	8.41	31.70	6.90	16.67
R01E1	5	2	5:1	rot	18.17	1.97	6.23	7.32	16.71
R01E1	6	2	10:1	rot	43.30	4.45	13.18	49.16	79.67
R01E1	7	2	5:1	ng	28.46	2.22	3.51	11.49	23.91
R01E1	8	2	10:1	ng	32.55	1.54	13.10	13.95	28.97
R01E1	9	2	NB	ng	18.32	1.98	0.24	10.77	19.42
R01E1	10	1	5:1	ng	44.97	11.86	1.36	22.04	51.26
R01E1	11	1	10:1	ng	148.11	12.93	39.25	16.65	62.20
R01E1	12	1	NB	ng	33.38	13.89	27.75	7.98	25.37
R01E1	13	1	5:1	con	5.11	8.19	0.20	54.19	60.35
R01E1	14	1	10:1	con	5.11				
R01E1	15	1	NB	con	4.88	8.33	1.52	44.56	51.90
R01E1	16	1	10:1	rot	16.28	11.55	36.03	10.14	27.99
R01E1	17	1	5:1	rot	3.33	4.39	0.00	8.48	10.96
R01E1	18	1	NB	rot	5.79	9.00	2.73	4.05	6.72
R01E1	19	3	NB	rot	21.73	15.79	6.37	12.16	17.16
R01E1	20	3	5:1	rot	24.98	21.82	1.36	15.59	24.73
R01E1	21	3	10:1	rot	7.95	5.60	2.81	2.47	5.88
R01E1	22	3	5:1	con	28.61	21.41	7.37	5.66	14.02
R01E1	23	3	10:1	con	19.08	7.98	4.64	3.58	11.83
R01E1	24	3	NB	con	20.40	7.86	9.15	5.75	21.63
R01E1	25	3	10:1	ng	24.53	2.34	24.91	17.83	34.83
R01E1	26	3	NB	ng	20.89	1.60	5.15	11.47	20.06
R01E1	27	3	5:1	ng	21.65	11.72	0.00	17.40	31.61

Table A6. Raw data on runoff volume and total losses of sediment, NO_3-N, PO_4-P, and total-P from grazing and VFS buffer treatments for rainfall event 8-3-01E2 at the ISU Rhodes Research Farm site, central Iowa, USA.

ID	Sample	Plot	Buffer ratio	Grazing practice	Runoff L	Solids g	NO_3-N mg	PO_4-P mg	Total-P mg
R01E2	1	2	10:1	con	37.32	14.44	1.55	18.88	23.51
R01E2	2	2	NB	con	20.44	8.83	13.48	18.42	23.30
R01E2	3	2	5:1	con	24.11	9.50	1.42	19.98	22.42
R01E2	4	2	NB	rot	16.28	0.74	0.00	4.65	10.74
R01E2	5	2	5:1	rot	21.20	0.64	4.53	2.16	8.27
R01E2	6	2	10:1	rot	3.33	0.41	0.74	1.96	2.90
R01E2	7	2	5:1	ng	12.45	2.98	1.72	3.31	8.09
R01E2	8	2	10:1	ng	14.65	2.97	11.05	8.47	13.77
R01E2	9	2	NB	ng	6.66	4.00	1.45	2.56	5.00
R01E2	10	1	5:1	ng	6.66	6.65	0.86	1.47	4.80
R01E2	11	1	10:1	ng	122.07	70.74	29.25	23.52	65.92
R01E2	12	1	NB	ng	34.97	18.76	0.00	16.12	38.12
R01E2	13	1	5:1	con	5.11	5.93	0.00	18.59	57.33
R01E2	14	1	10:1	con	18.74	7.86	28.89	10.55	17.42
R01E2	15	1	NB	con	53.71	22.97	153.45	38.14	57.47
R01E2	16	1	10:1	rot	105.79	18.83	260.16	45.91	71.94
R01E2	17	1	5:1	rot	68.28	8.47	73.70	18.27	35.51
R01E2	18	1	NB	rot	13.51	7.20	8.91	5.55	15.00
R01E2	19	3	NB	rot	45.00	8.10	20.59	45.66	59.40
R01E2	20	3	5:1	rot	19.98	20.58	5.81	3.03	8.79
R01E2	21	3	10:1	rot	9.54	0.29	3.01	1.54	2.77
R01E2	22	3	5:1	con	23.85	18.27	19.05	7.21	14.78
R01E2	23	3	10:1	con	13.63	9.46	4.31	1.05	3.68
R01E2	24	3	NB	con	14.84	8.12	7.15	1.60	5.93
R01E2	25	3	10:1	ng	16.35	0.85	1.28	21.42	24.85
R01E2	26	3	NB	ng	15.67	1.65	0.00	25.28	6.74
R01E2	27	3	5:1	ng	1.97	1.18	0.00	3.75	4.94

Table A7. Raw data on runoff volume and total losses of sediment, NO_3-N, PO_4-P, and total-P from grazing and VFS buffer treatments for rainfall event 9-7-01E3 at the ISU Rhodes Research Farm site, central Iowa, USA.

ID	Sample	Plot	Buffer ratio	Grazing practice	Runoff L	Solids g	NO_3-N mg	PO_4-P mg	Total-P mg
R01E3	1	2	10:1	con	17.56	40.51	0.15	6.22	13.17
R01E3	2	2	NB	con	18.74	17.87	1.15	5.32	8.06
R01E3	3	2	5:1	con	5.56	4.30	0.92	1.55	3.45
R01E3	4	2	NB	rot	14.65	11.21	0.00	5.18	14.94
R01E3	5	2	5:1	rot	4.54	2.88	0.26	2.32	4.18
R01E3	6	2	10:1	rot	8.33	1.33	0.94	4.34	2.00
R01E3	7	2	5:1	ng	5.34	12.51	0.00	3.56	12.49
R01E3	8	2	10:1	ng	19.53	22.98	0.31	4.75	33.98
R01E3	9	2	NB	ng	8.33	5.57	1.90	6.73	10.91
R01E3	10	1	5:1	ng	18.32	22.23	0.61	2.79	4.40
R01E3	11	1	10:1	ng	61.85	15.68	6.24	9.43	18.55
R01E3	12	1	NB	ng	60.41	86.02	0.83	3.33	40.47
R01E3	13	1	5:1	con	390.04	105.88	159.79	406.34	526.56
R01E3	14	1	10:1	con	345.76	71.46	320.62	201.73	311.18
R01E3	15	1	NB	con	315.74	173.27	298.07	261.00	432.57
R01E3	16	1	10:1	rot	462.22	86.91	744.99	320.27	406.76
R01E3	17	1	5:1	rot	216.50	27.38	128.92	80.56	88.77
R01E3	18	1	NB	rot	183.38	180.52	194.84	54.90	100.86
R01E3	19	3	NB	rot	35.69	6.78	4.13	24.86	32.84
R01E3	20	3	5:1	rot	18.32	21.83	0.35	6.71	19.24
R01E3	21	3	10:1	rot	19.08	2.58	5.15	5.67	9.54
R01E3	22	3	5:1	con	15.90	23.03	1.54	6.08	19.71
R01E3	23	3	10:1	con	173.73	229.63	124.01	47.79	76.44
R01E3	24	3	NB	con	365.37	132.70	525.41	163.74	299.60
R01E3	25	3	10:1	ng	14.31	0.72	2.90	8.37	40.49
R01E3	26	3	NB	ng	13.93	23.60	25.75	25.21	46.52
R01E3	27	3	5:1	ng	9.84	9.19	10.26	26.41	31.49

Table A8. Raw data on runoff volume and total losses of sediment, NO_3-N, PO_4-P, and total-P from grazing and VFS buffer treatments for rainfall event 10-22-01E4 at the ISU Rhodes Research Farm site, central Iowa, USA.

ID	Sample	Plot	Buffer ratio	Grazing practice	Runoff L	Solids g	NO_3-N mg	PO_4-P mg	Total-P mg
R01E4	1	2	10:1	con	0.00	0.00			
R01E4	2	2	NB	con	0.00	0.00			
R01E4	3	2	5:1	con	3.71	1.07	0.46	5.82	7.23
R01E4	4	2	NB	rot	4.88	0.68	0.88	4.24	4.54
R01E4	5	2	5:1	rot	0.00	0.00	0.00	0.00	0.00
R01E4	6	2	10:1	rot	3.33	0.36	1.33	3.34	3.46
R01E4	7	2	5:1	ng	5.34	4.88	0.00	12.27	17.08
R01E4	8	2	10:1	ng	3.26	1.38	1.64	6.53	6.77
R01E4	9	2	NB	ng	0.00	0.00			
R01E4	10	1	5:1	ng	23.32	8.59	0.48	5.08	9.56
R01E4	11	1	10:1	ng	48.83	12.44	7.62	12.03	16.60
R01E4	12	1	NB	ng	71.54	9.06	4.35	13.75	82.27
R01E4	13	1	5:1	con	45.99	18.58	18.24	32.29	49.21
R01E4	14	1	10:1	con	0.00	0.00			
R01E4	15	1	NB	con	0.00	0.00			
R01E4	16	1	10:1	rot	213.21	86.37	105.52	125.51	215.34
R01E4	17	1	5:1	rot	141.56	50.20	31.20	65.51	97.68
R01E4	18	1	NB	rot	162.15	200.72	63.72	57.34	218.90
R01E4	19	3	NB	rot	83.80	10.78	20.25	55.49	56.15
R01E4	20	3	5:1	rot	13.32	8.99	0.49	7.53	16.39
R01E4	21	3	10:1	rot	71.54	6.79	37.90	72.07	72.97
R01E4	22	3	5:1	con	41.33	33.67	6.54	17.67	24.80
R01E4	23	3	10:1	con	0.00	0.00			
R01E4	24	3	NB	con	129.83	0.00	319.35	0.00	0.00
R01E4	25	3	10:1	ng	10.22	1.35	2.46	4.84	6.44
R01E4	26	3	NB	ng	36.56	12.08	1.17	11.98	30.71
R01E4	27	3	5:1	ng	33.46	15.45	1.53	60.33	69.26

Table A9. Raw data on runoff depth and concentrations of sediment, NO_3-N, PO_4-P, and total-P from grazing and VFS buffer treatments for rainfall event 6-12-02E5 at the ISU Rhodes Research Farm site, central Iowa, USA.

ID	Sample	Plot	Buffer ratio	Grazing practice	Runoff mm	Solids g/kg	NO_3-N mg/L	PO_4-P mg/L	Total-P mg/L
R02E5	1	2	10:1	con	2.14				
R02E5	2	2	NB	con	0.00				
R02E5	3	2	5:1	con	0.00				
R02E5	4	2	NB	rot	1.74	0.26	0.51	0.21	0.74
R02E5	5	2	5:1	rot	0.12	0.16	0.05	0.72	0.99
R02E5	6	2	10:1	rot	0.06	0.17	0.22	0.15	0.89
R02E5	7	2	5:1	ng	0.03	0.41	0.46	0.06	0.84
R02E5	8	2	10:1	ng	0.06	0.31	0.26	0.08	0.79
R02E5	9	2	NB	ng	0.03	0.14	0.40	0.08	0.64
R02E5	10	1	5:1	ng	1.27	0.51	0.03	4.56	6.94
R02E5	11	1	10:1	ng	5.29	0.16	0.00	1.87	3.24
R02E5	12	1	NB	ng	2.98	0.34	0.00	0.89	3.09
R02E5	13	1	5:1	con	0.03	0.60	0.82	1.43	5.29
R02E5	14	1	10:1	con	0.03	1.08	0.00	5.63	1.74
R02E5	15	1	NB	con	20.84	1.22	0.02	0.25	2.54
R02E5	16	1	10:1	rot	3.22	0.16	2.29	0.66	1.19
R02E5	17	1	5:1	rot	12.17	0.27	0.03	0.79	1.19
R02E5	18	1	NB	rot	11.58	0.12	1.11	0.46	1.19
R02E5	19	3	NB	rot	7.18	0.42	0.00	1.50	2.84
R02E5	20	3	5:1	rot	5.86	0.87	0.10	0.18	0.39
R02E5	21	3	10:1	rot	6.38	0.08	0.38	0.04	0.39
R02E5	22	3	5:1	con	7.16	0.17	0.00	0.72	1.89
R02E5	23	3	10:1	con		0.02	0.62	0.11	0.54
R02E5	24	3	NB	con	14.50	0.20	0.61	0.05	0.34
R02E5	25	3	10:1	ng	5.47	0.23	0.00	1.46	2.59
R02E5	26	3	NB	ng	11.21		0.80	2.36	2.74
R02E5	27	3	5:1	ng	19.31		0.65	0.26	1.89

Table A10. Raw data on runoff depth and concentrations of sediment, NO_3-N, PO_4-P, and total-P from grazing and VFS buffer treatments for rainfall event 7-10-02E6 at the ISU Rhodes Research Farm site, central Iowa, USA.

ID	Sample	Plot	Buffer ratio	Grazing practice	Runoff mm	Solids g/kg	NO_3-N mg/L	PO_4-P mg/L	Total-P mg/L
R02E6	1	2	10:1	con	0.19	0.27	0.94	0.30	0.94
R02E6	2	2	NB	con	0.29	0.29	0.06	0.43	0.99
R02E6	3	2	5:1	con	0.27	1.48	0.00	1.36	3.84
R02E6	4	2	NB	rot	0.31	0.11	0.24	0.17	0.69
R02E6	5	2	5:1	rot	0.05	0.13	0.05	0.31	0.89
R02E6	6	2	10:1	rot	0.14	0.18	0.06	1.06	2.19
R02E6	7	2	5:1	ng	0.00	0.20	0.30	0.65	1.14
R02E6	8	2	10:1	ng	0.23	0.47	0.00	1.71	2.94
R02E6	9	2	NB	ng	0.16	0.52	0.06	4.19	3.29
R02E6	10	1	5:1	ng	0.03	0.18	1.10	0.24	0.79
R02E6	11	1	10:1	ng	0.14	0.14	0.90	0.21	0.59
R02E6	12	1	NB	ng	0.27	0.13	0.00	0.07	1.09
R02E6	13	1	5:1	con	0.08	0.31	0.65	0.53	1.09
R02E6	14	1	10:1	con	0.12	0.34	0.80	0.54	1.34
R02E6	15	1	NB	con	0.22	0.25	1.13	1.64	2.14
R02E6	16	1	10:1	rot	0.20	0.21	0.99	0.42	0.84
R02E6	17	1	5:1	rot	0.08	0.17	0.35	0.29	0.64
R02E6	18	1	NB	rot	0.15	0.31	0.38	0.32	1.19
R02E6	19	3	NB	rot	0.36	0.08	0.89	0.36	0.84
R02E6	20	3	5:1	rot	0.13	0.14	0.00	0.20	0.69
R02E6	21	3	10:1	rot	0.25	0.21	0.35	0.99	1.24
R02E6	22	3	5:1	con	0.23	0.28	0.00	0.38	1.19
R02E6	23	3	10:1	con	0.06	0.15	0.34	0.71	0.64
R02E6	24	3	NB	con	0.18	0.21	1.44	0.29	0.84
R02E6	25	3	10:1	ng	0.04	0.15	0.97	0.28	0.74
R02E6	26	3	NB	ng	0.23	0.15	0.38	0.16	0.84
R02E6	27	3	5:1	ng	0.03	0.52	0.04	0.57	1.44

Table A11. Raw data on runoff depth and concentrations of sediment, NO_3-N, PO_4-P, and total-P from grazing and VFS buffer treatments for rainfall event 8-23-02E7 at the ISU Rhodes Research Farm site, central Iowa, USA.

ID	Sample	Plot	Buffer ratio	Grazing practice	Runoff mm	Solids g/kg	NO_3-N mg/L	PO_4-P mg/L	Total-P mg/L
R02E7	1	2	10:1	con	0.04	0.35	0.00	5.59	5.14
R02E7	2	2	NB	con	0.03	0.20	3.44	1.87	1.79
R02E7	3	2	5:1	con	0.06	0.23	5.40	1.58	1.74
R02E7	4	2	NB	rot	0.12	0.22	8.69	2.43	2.64
R02E7	5	2	5:1	rot	0.12	0.16	0.99	0.76	1.94
R02E7	6	2	10:1	rot	0.06	0.19	1.19	1.42	1.94
R02E7	7	2	5:1	ng	0.08	0.17	7.04	1.85	2.09
R02E7	8	2	10:1	ng	0.06	0.13	2.74	0.32	1.44
R02E7	9	2	NB	ng	0.22	0.21	4.91	1.98	1.89
R02E7	10	1	5:1	ng	0.11	0.38	6.48	2.86	3.04
R02E7	11	1	10:1	ng	0.17	0.20	1.92	0.78	0.89
R02E7	12	1	NB	ng	0.15	0.22	6.96	1.27	1.29
R02E7	13	1	5:1	con	0.03	1.11	0.51	12.85	11.34
R02E7	14	1	10:1	con	0.06	3.06	1.96	4.29	9.84
R02E7	15	1	NB	con	0.44	0.73	18.44	4.94	5.94
R02E7	16	1	10:1	rot		0.37	3.69	5.02	2.74
R02E7	17	1	5:1	rot	0.24	0.37	12.34	6.74	6.09
R02E7	18	1	NB	rot	0.04	0.24	3.42	1.18	0.94
R02E7	19	3	NB	rot	0.06	0.12	7.08	1.73	1.39
R02E7	20	3	5:1	rot	0.11	0.21	0.00	2.16	1.64
R02E7	21	3	10:1	rot	0.11	0.14	3.41	0.75	2.29
R02E7	22	3	5:1	con	0.00	0.10	2.97	1.10	1.39
R02E7	23	3	10:1	con	0.18	0.07	0.84	1.10	1.04
R02E7	24	3	NB	con	0.18	0.09	3.68	0.70	0.64
R02E7	25	3	10:1	ng	0.14	0.28	4.37	3.17	2.99
R02E7	26	3	NB	ng	0.10	0.35	8.86	2.67	2.89
R02E7	27	3	5:1	ng	0.16	0.57	17.72	5.97	6.64

Table A12. Raw data on runoff volume and total losses of sediment, NO_3-N, PO_4-P, and total-P from grazing and VFS buffer treatments for rainfall event 6-12-02E5 at the ISU Rhodes Research Farm site, central Iowa, USA.

ID	Sample	Plot	Buffer ratio	Grazing practice	Runoff L	Solids g	NO_3-N mg	PO_4-P mg	Total-P mg
R02E5	1	2	10:1	con	122.94				
R02E5	2	2	NB	con	0.00				
R02E5	3	2	5:1	con	0.00				
R02E5	4	2	NB	rot	91.14	23.69	46.61	19.00	67.45
R02E5	5	2	5:1	rot	7.57	1.19	0.40	5.42	7.49
R02E5	6	2	10:1	rot	3.33	0.55	0.72	0.51	2.96
R02E5	7	2	5:1	ng	1.78	0.72	0.83	0.11	1.49
R02E5	8	2	10:1	ng	3.26	1.00	0.83	0.26	2.57
R02E5	9	2	NB	ng	1.67	0.24	0.66	0.13	1.07
R02E5	10	1	5:1	ng	79.94	40.46	2.10	364.39	554.78
R02E5	11	1	10:1	ng	304.35	48.55	0.00	568.15	986.10
R02E5	12	1	NB	ng	155.79	53.01	0.00	138.25	481.39
R02E5	13	1	5:1	con	1.70	1.03	1.41	2.43	9.01
R02E5	14	1	10:1	con	1.70	1.84	0.00	9.58	2.96
R02E5	15	1	NB	con	1090.46	1323.82	25.49	269.70	2769.76
R02E5	16	1	10:1	rot	185.54	29.83	425.32	122.94	220.79
R02E5	17	1	5:1	rot	764.42	205.77	23.19	605.55	909.66
R02E5	18	1	NB	rot	606.13	70.01	672.48	279.14	721.29
R02E5	19	3	NB	rot	375.55	157.70	0.00	562.13	1066.56
R02E5	20	3	5:1	rot	368.05	321.12	37.53	67.85	143.54
R02E5	21	3	10:1	rot	367.22	28.96	140.81	15.87	143.22
R02E5	22	3	5:1	con	449.89	78.14	0.00	325.29	850.28
R02E5	23	3	10:1	con	0.00	0.00	0.00	0.00	0.00
R02E5	24	3	NB	con	758.55	154.04	465.36	38.28	257.91
R02E5	25	3	10:1	ng	314.76	70.89	0.00	460.75	815.23
R02E5	26	3	NB	ng	586.75		470.44	1386.08	1607.70
R02E5	27	3	5:1	ng	1212.41		787.79	312.40	2291.46

Table A13. Raw data on runoff volume and total losses of sediment, NO_3-N, PO_4-P, and total-P from grazing and VFS buffer treatments for rainfall event 7-10-02E6 at the ISU Rhodes Research Farm site, central Iowa, USA.

ID	Sample	Plot	Buffer ratio	Grazing practice	Runoff L	Solids g	NO_3-N mg	PO_4-P mg	Total-P mg
R02E6	1	2	10:1	con	10.98	3.00	10.27	3.25	10.32
R02E6	2	2	NB	con	15.33	4.46	0.96	6.54	15.18
R02E6	3	2	5:1	con	16.69	24.69	0.00	22.68	64.10
R02E6	4	2	NB	rot	16.28	1.85	3.88	2.81	11.23
R02E6	5	2	5:1	rot	3.03	0.40	0.14	0.95	2.69
R02E6	6	2	10:1	rot	8.33	1.49	0.49	8.83	18.24
R02E6	7	2	5:1	ng	0.00	0.00			
R02E6	8	2	10:1	ng	13.02	6.11	0.00	22.22	38.28
R02E6	9	2	NB	ng	8.33	4.37	0.48	34.90	27.40
R02E6	10	1	5:1	ng	1.67	0.30	1.84	0.41	1.32
R02E6	11	1	10:1	ng	8.14	1.17	7.32	1.73	4.80
R02E6	12	1	NB	ng	14.31	1.88	0.00	1.04	15.59
R02E6	13	1	5:1	con	5.11	1.60	3.33	2.72	5.57
R02E6	14	1	10:1	con	6.81	2.32	5.48	3.68	9.13
R02E6	15	1	NB	con	11.39	2.85	12.82	18.65	24.38
R02E6	16	1	10:1	rot	11.39	2.36	11.27	4.82	9.57
R02E6	17	1	5:1	rot	5.00	0.84	1.75	1.46	3.20
R02E6	18	1	NB	rot	7.72	2.36	2.95	2.48	9.19
R02E6	19	3	NB	rot	18.62	1.48	16.66	6.70	15.64
R02E6	20	3	5:1	rot	8.33	1.16	0.00	1.65	5.75
R02E6	21	3	10:1	rot	14.31	2.99	4.99	14.18	17.74
R02E6	22	3	5:1	con	14.31	4.00	0.00	5.38	17.03
R02E6	23	3	10:1	con	3.41	0.52	1.16	2.43	2.18
R02E6	24	3	NB	con	9.27	1.95	13.37	2.65	7.79
R02E6	25	3	10:1	ng	2.04	0.31	1.99	0.57	1.51
R02E6	26	3	NB	ng	12.19	1.88	4.64	1.93	10.24
R02E6	27	3	5:1	ng	1.97	1.03	0.08	1.11	2.83

Table A14. Raw data on runoff volume and total losses of sediment, NO_3-N, PO_4-P, and total-P from grazing and VFS buffer treatments for rainfall event 8-23-02E7 at the ISU Rhodes Research Farm site, central Iowa, USA.

ID	Sample	Plot	Buffer ratio	Grazing practice	Runoff L	Solids g	NO_3-N mg	PO_4-P mg	Total-P mg
R02E7	1	2	10:1	con	2.20	0.77	0.00	12.28	11.28
R02E7	2	2	NB	con	1.70	0.35	5.86	3.19	3.05
R02E7	3	2	5:1	con	3.71	0.87	20.03	5.85	6.45
R02E7	4	2	NB	rot	6.51	1.46	56.59	15.83	17.19
R02E7	5	2	5:1	rot	7.57	1.18	7.50	5.75	14.69
R02E7	6	2	10:1	rot	3.33	0.62	3.95	4.73	6.46
R02E7	7	2	5:1	ng	5.34	0.89	37.58	9.85	11.15
R02E7	8	2	10:1	ng	3.26	0.41	8.93	1.04	4.69
R02E7	9	2	NB	ng	11.66	2.40	57.27	23.10	22.03
R02E7	10	1	5:1	ng	6.66	2.53	43.17	19.04	20.25
R02E7	11	1	10:1	ng	9.77	1.99	18.72	7.64	8.69
R02E7	12	1	NB	ng	7.95	1.77	55.29	10.09	10.25
R02E7	13	1	5:1	con	1.70	1.89	0.87	21.88	19.31
R02E7	14	1	10:1	con	3.41	10.41	6.67	14.60	33.52
R02E7	15	1	NB	con	22.79	16.63	420.19	112.51	135.35
R02E7	16	1	10:1	rot	0.00				
R02E7	17	1	5:1	rot	14.99	5.50	184.98	100.97	91.28
R02E7	18	1	NB	rot	1.93	0.46	6.61	2.28	1.81
R02E7	19	3	NB	rot	3.10	0.38	21.97	5.36	4.31
R02E7	20	3	5:1	rot	6.66	1.37	0.00	14.40	10.93
R02E7	21	3	10:1	rot	6.36	0.87	21.67	4.75	14.56
R02E7	22	3	5:1	con	0.00	0.00	0.00	0.00	0.00
R02E7	23	3	10:1	con	10.22	0.70	8.54	11.29	10.63
R02E7	24	3	NB	con	9.27	0.81	34.09	6.51	5.93
R02E7	25	3	10:1	ng	8.18	2.33	35.71	25.94	24.45
R02E7	26	3	NB	ng	5.22	1.81	46.30	13.92	15.10
R02E7	27	3	5:1	ng	9.84	5.58	174.37	58.70	65.34

Table A15. Raw data on runoff depth and concentrations of sediment, NO_3-N, PO_4-P, and total-P from grazing and VFS buffer treatments for rainfall event 5-4-03E8 at the ISU Rhodes Research Farm site, central Iowa, USA.

ID	Sample	Plot	Buffer ratio	Grazing practice	Runoff mm	Solids g/kg	NO_3-N mg/L	PO_4-P mg/L	Total-P mg/L
R03E8	1	2	10:1	con	5.95				
R03E8	2	2	NB	con	0.13				
R03E8	3	2	5:1	con	0.24				
R03E8	4	2	NB	rot	0.78	0.56	0.33	0.07	0.00
R03E8	5	2	5:1	rot	1.21				
R03E8	6	2	10:1	rot	0.81	0.07	0.56	0.48	0.49
R03E8	7	2	5:1	ng	0.74				
R03E8	8	2	10:1	ng	3.11	0.09	0.28	1.40	1.37
R03E8	9	2	NB	ng	1.43	0.28	0.18	1.83	1.50
R03E8	10	1	5:1	ng	0.40	0.22	0.08	1.88	1.50
R03E8	11	1	10:1	ng	0.48	0.29	0.86	0.31	0.45
R03E8	12	1	NB	ng	5.07	0.12	0.60	0.42	0.40
R03E8	13	1	5:1	con		0.13	0.69	0.45	1.05
R03E8	14	1	10:1	con	1.15	0.26	0.18	0.66	0.68
R03E8	15	1	NB	con	3.79	0.24	0.34	0.92	0.91
R03E8	16	1	10:1	rot	1.16	0.15	0.55	0.51	0.50
R03E8	17	1	5:1	rot		0.20	1.00	0.34	0.36
R03E8	18	1	NB	rot	18.52	0.13	0.08	0.80	0.00
R03E8	19	3	NB	rot	1.99	0.19	0.33	0.31	0.38
R03E8	20	3	5:1	rot	7.24	0.35	0.32	2.89	1.50
R03E8	21	3	10:1	rot	1.77	0.25	0.55	0.52	0.62
R03E8	22	3	5:1	con	1.92	0.08	0.32	0.24	0.29
R03E8	23	3	10:1	con	1.48	0.36	0.11	0.94	1.05
R03E8	24	3	NB	con	0.89	0.30	0.13	0.22	0.30
R03E8	25	3	10:1	ng	6.25	0.37	0.15	0.23	0.37
R03E8	26	3	NB	ng	25.46	0.37	0.15	0.10	0.22
R03E8	27	3	5:1	ng	5.30	0.22	0.44	0.12	0.34

Table A16. Raw data on runoff depth and concentrations of sediment, NO_3-N, PO_4-P, and total-P from grazing and VFS buffer treatments for rainfall event 6-25-03E9 at the ISU Rhodes Research Farm site, central Iowa, USA.

ID	Sample	Plot	Buffer ratio	Grazing practice	Runoff mm	Solids g/kg	NO_3-N mg/L	PO_4-P mg/L	Total-P mg/L
R03E9	1	2	10:1	con	0.19	0.63	0.00	3.51	5.20
R03E9	2	2	NB	con	0.03	0.15	0.00	0.48	0.53
R03E9	3	2	5:1	con	0.03	0.21	0.02	0.39	0.81
R03E9	4	2	NB	rot	0.16	0.20	0.45	0.08	0.04
R03E9	5	2	5:1	rot	0.02	0.29	0.01	0.33	0.42
R03E9	6	2	10:1	rot	0.12	0.10	0.21	0.05	0.00
R03E9	7	2	5:1	ng	0.11	0.20	2.18	0.23	0.20
R03E9	8	2	10:1	ng	0.11	0.19	0.87	1.02	1.00
R03E9	9	2	NB	ng	0.03	0.23	2.27	0.17	0.12
R03E9	10	1	5:1	ng	0.13	0.49	0.00	3.03	2.30
R03E9	11	1	10:1	ng	0.11	0.17	1.00	0.16	0.19
R03E9	12	1	NB	ng	0.12	0.28	0.02	0.61	0.64
R03E9	13	1	5:1	con	0.08	0.24	1.38	0.27	0.26
R03E9	14	1	10:1	con	0.15	0.12	0.05	0.91	0.25
R03E9	15	1	NB	con	0.16	0.34	0.13	0.98	0.98
R03E9	16	1	10:1	rot	0.03	0.07	0.39	0.54	0.53
R03E9	17	1	5:1	rot	0.13	0.16	0.14	0.61	0.62
R03E9	18	1	NB	rot	0.22	0.38	1.11	0.42	0.33
R03E9	19	3	NB	rot	0.12	0.56	0.13	3.42	4.10
R03E9	20	3	5:1	rot	0.13	0.23	0.20	0.38	0.41
R03E9	21	3	10:1	rot		0.16	0.65	0.53	0.53
R03E9	22	3	5:1	con	0.13	0.19	0.43	0.21	0.23
R03E9	23	3	10:1	con	0.03	0.17	0.47	0.16	0.16
R03E9	24	3	NB	con	0.04	0.25	0.09	0.16	0.18
R03E9	25	3	10:1	ng	0.04	0.22	0.25	0.08	0.14
R03E9	26	3	NB	ng		0.17	0.38	0.08	0.18
R03E9	27	3	5:1	ng	0.03	0.27	0.31	0.08	0.37

Table A17. Raw data on runoff depth and concentrations of sediment, NO_3-N, PO_4-P, and total-P from grazing and VFS buffer treatments for rainfall event 7-5-03E10 at the ISU Rhodes Research Farm site, central Iowa, USA.

ID	Sample	Plot	Buffer ratio	Grazing practice	Runoff mm	Solids g/kg	NO_3-N mg/L	PO_4-P mg/L	Total-P mg/L
R03E10	1	2	10:1	con	0.15	0.17	3.81	2.80	2.90
R03E10	2	2	NB	con	0.07	0.07	1.70	0.91	0.91
R03E10	3	2	5:1	con	0.06	0.12	5.92	2.07	2.10
R03E10	4	2	NB	rot	0.75	0.11	0.71	0.08	0.11
R03E10	5	2	5:1	rot	0.02	0.22	6.04	3.03	3.10
R03E10	6	2	10:1	rot	0.03	0.16	3.87	0.55	0.64
R03E10	7	2	5:1	ng	0.17	0.23	8.79	1.55	1.53
R03E10	8	2	10:1	ng	0.08	0.07	3.53	0.35	0.40
R03E10	9	2	NB	ng	0.19	0.20	8.15	1.64	1.61
R03E10	10	1	5:1	ng	0.16	0.08	1.79	0.71	0.66
R03E10	11	1	10:1	ng	0.20	0.19	5.36	1.34	1.28
R03E10	12	1	NB	ng	0.12	0.06	1.51	0.36	0.43
R03E10	13	1	5:1	con	0.11	0.11	2.15	1.05	0.98
R03E10	14	1	10:1	con	0.24	0.33	7.77	6.28	6.40
R03E10	15	1	NB	con	1.68	0.15	1.55	1.03	0.96
R03E10	16	1	10:1	rot	0.71	0.08	0.95	0.72	0.70
R03E10	17	1	5:1	rot	1.83	0.07	0.82	0.60	0.59
R03E10	18	1	NB	rot	0.22	0.10	0.71	0.29	0.31
R03E10	19	3	NB	rot	4.80	0.07	0.33	0.49	0.46
R03E10	20	3	5:1	rot	0.93	0.20	1.14	0.79	0.82
R03E10	21	3	10:1	rot		0.12	0.95	0.73	0.73
R03E10	22	3	5:1	con	0.91	0.15	1.72	0.41	0.46
R03E10	23	3	10:1	con	0.47	0.15	0.58	0.52	0.54
R03E10	24	3	NB	con	0.53	0.18	1.49	0.48	0.53
R03E10	25	3	10:1	ng	0.11	0.09	1.44	1.19	1.12
R03E10	26	3	NB	ng	0.07	0.10	0.55	0.41	0.47
R03E10	27	3	5:1	ng	0.16	0.31	0.33	3.84	3.80

Table A18. Raw data on runoff depth and concentrations of sediment, NO_3-N, PO_4-P, and total-P from grazing and VFS buffer treatments for rainfall event 9-12-03E11 at the ISU Rhodes Research Farm site, central Iowa, USA.

ID	Sample	Plot	Buffer ratio	Grazing practice	Runoff mm	Solids g/kg	NO_3-N mg/L	PO_4-P mg/L	Total-P mg/L
R03E11	1	2	10:1	con	0.15	0.16	0.29	3.04	0.82
R03E11	2	2	NB	con	0.03	0.07	0.29	1.37	1.27
R03E11	3	2	5:1	con	0.03	0.19	0.36	4.32	4.94
R03E11	4	2	NB	rot	0.06	0.84	0.00	11.03	11.94
R03E11	5	2	5:1	rot	0.02	0.31	3.41	5.45	5.24
R03E11	6	2	10:1	rot	0.03	0.59	0.07	11.82	12.25
R03E11	7	2	5:1	ng	0.06	0.10	0.82	1.36	1.34
R03E11	8	2	10:1	ng	0.11	0.07	1.11	0.46	0.49
R03E11	9	2	NB	ng	0.13	1.40	27.41	21.77	22.70
R03E11	10	1	5:1	ng	0.03	0.09	2.52	0.89	0.96
R03E11	11	1	10:1	ng	0.03	0.06	2.56	0.37	0.42
R03E11	12	1	NB	ng	0.03	0.05	0.36	0.20	0.20
R03E11	13	1	5:1	con	0.03	0.68	1.40	5.39	6.04
R03E11	14	1	10:1	con	0.03	0.71	0.00	7.08	8.14
R03E11	15	1	NB	con	0.44	0.09	0.41	1.09	1.12
R03E11	16	1	10:1	rot	0.03	0.09	2.29	0.94	0.98
R03E11	17	1	5:1	rot	0.16	0.15	4.29	2.18	2.74
R03E11	18	1	NB	rot	0.04	0.04	0.18	0.14	0.12
R03E11	19	3	NB	rot	2.88	0.05	0.40	0.51	0.49
R03E11	20	3	5:1	rot	0.11	0.06	0.13	0.20	0.29
R03E11	21	3	10:1	rot	0.22	0.10	0.57	0.98	0.97
R03E11	22	3	5:1	con	0.05	0.11	0.21	0.20	0.33
R03E11	23	3	10:1	con	0.03	0.26	1.20	2.96	3.63
R03E11	24	3	NB	con	0.04	0.25	0.04	3.13	3.93
R03E11	25	3	10:1	ng	0.04	0.62	0.00	2.44	3.63
R03E11	26	3	NB	ng	0.07	1.57	0.00	3.61	5.73
R03E11	27	3	5:1	ng					

Table A19. Raw data on runoff depth and concentrations of sediment, NO_3-N, PO_4-P, and total-P from grazing and VFS buffer treatments for rainfall event 11-4-03E12 at the ISU Rhodes Research Farm site, central Iowa, USA.

ID	Sample	Plot	Buffer ratio	Grazing practice	Runoff mm	Solids g/kg	NO_3-N mg/L	PO_4-P mg/L	Total-P mg/L
R03E12	1	2	10:1	con	0.04	0.17	0.34	1.48	1.32
R03E12	2	2	NB	con	0.42	0.02	0.18	0.12	0.10
R03E12	3	2	5:1	con	0.12	0.46	0.07	19.95	17.34
R03E12	4	2	NB	rot	0.47	0.14	8.44	2.63	2.87
R03E12	5	2	5:1	rot	0.05	0.14	1.46	0.55	6.07
R03E12	6	2	10:1	rot	0.14	0.11	0.79	1.74	1.61
R03E12	7	2	5:1	ng	0.00	0.11	1.35	1.78	1.62
R03E12	8	2	10:1	ng	2.69	0.20	3.98	0.71	0.78
R03E12	9	2	NB	ng	1.62	0.24	1.87	0.48	0.48
R03E12	10	1	5:1	ng	0.05	0.11	0.76	0.63	0.62
R03E12	11	1	10:1	ng	6.98	0.17	0.77	0.16	0.22
R03E12	12	1	NB	ng	7.35	0.24	0.29	0.12	0.19
R03E12	13	1	5:1	con	0.08	0.10	0.39	0.58	0.55
R03E12	14	1	10:1	con	0.36	0.18	0.68	0.81	0.71
R03E12	15	1	NB	con	16.08	0.18	0.11	1.05	0.94
R03E12	16	1	10:1	rot	23.19	0.10	0.15	0.53	0.52
R03E12	17	1	5:1	rot	9.20	0.12	0.18	0.42	0.40
R03E12	18	1	NB	rot	0.07	0.17	0.09	0.25	0.13
R03E12	19	3	NB	rot	22.57	0.16	0.14	0.26	0.33
R03E12	20	3	5:1	rot	7.67	0.12	0.11	0.24	0.23
R03E12	21	3	10:1	rot	12.93	0.11	0.26	0.33	0.34
R03E12	22	3	5:1	con	3.92	0.11	0.19	0.39	0.38
R03E12	23	3	10:1	con	5.53	0.09	0.13	0.36	0.36
R03E12	24	3	NB	con	1.52	0.17	0.13	0.19	0.17
R03E12	25	3	10:1	ng	62.53	0.17	0.21	0.10	0.15
R03E12	26	3	NB	ng	23.16	0.13	0.17	0.11	0.11
R03E12	27	3	5:1	ng		0.16	0.15	0.15	0.14

Table A20. Raw data on runoff volume and total losses of sediment, NO_3-N, PO_4-P, and total-P from grazing and VFS buffer treatments for rainfall event 5-4-03E8 at the ISU Rhodes Research Farm site, central Iowa, USA.

ID	Sample	Plot	Buffer ratio	Grazing practice	Runoff L	Solids g	NO_3-N mg	PO_4-P mg	Total-P mg
R03E8	1	2	10:1	con	342.47				
R03E8	2	2	NB	con	6.81				
R03E8	3	2	5:1	con	14.84				
R03E8	4	2	NB	rot	40.69	22.69	13.43	2.89	0.00
R03E8	5	2	5:1	rot	75.70				
R03E8	6	2	10:1	rot	46.63	3.18	26.11	22.38	22.85
R03E8	7	2	5:1	ng	46.25				
R03E8	8	2	10:1	ng	179.03	16.68	50.13	250.64	245.27
R03E8	9	2	NB	ng	74.94	21.30	13.49	137.15	112.41
R03E8	10	1	5:1	ng	24.98	5.54	2.00	46.96	37.47
R03E8	11	1	10:1	ng	27.67	7.95	23.79	8.58	12.45
R03E8	12	1	NB	ng	265.48	30.97	159.29	111.50	106.19
R03E8	13	1	5:1	con					
R03E8	14	1	10:1	con	66.43	17.42	11.96	43.84	45.17
R03E8	15	1	NB	con	198.56	48.17	67.51	182.68	180.69
R03E8	16	1	10:1	rot	66.73	9.99	36.70	34.03	33.36
R03E8	17	1	5:1	rot					
R03E8	18	1	NB	rot	969.04	126.04	77.52	775.23	0.00
R03E8	19	3	NB	rot	103.97	19.99	34.31	32.23	39.51
R03E8	20	3	5:1	rot	454.65	160.73	145.49	1313.95	681.98
R03E8	21	3	10:1	rot	101.74	25.37	55.96	52.91	63.08
R03E8	22	3	5:1	con	120.82	9.76	38.66	29.00	35.04
R03E8	23	3	10:1	con	85.16	30.29	9.37	80.05	89.42
R03E8	24	3	NB	con	46.37	13.91	6.03	10.20	13.91
R03E8	25	3	10:1	ng	359.73	131.28	53.96	82.74	133.10
R03E8	26	3	NB	ng	1331.94	485.73	199.79	134.53	293.03
R03E8	27	3	5:1	ng	332.63	74.35	146.36	41.25	113.09

Table A21. Raw data on runoff volume and total losses of sediment, NO_3-N, PO_4-P, and total-P from grazing and VFS buffer treatments for rainfall event 6-25-03E9 at the ISU Rhodes Research Farm site, central Iowa, USA.

ID	Sample	Plot	Buffer ratio	Grazing practice	Runoff L	Solids g	NO_3-N mg	PO_4-P mg	Total-P mg
R03E9	1	2	10:1	con	10.98	6.94	0.00	38.52	57.08
R03E9	2	2	NB	con	1.70	0.26	0.00	0.82	0.91
R03E9	3	2	5:1	con	1.85	0.38	0.04	0.73	1.50
R03E9	4	2	NB	rot	8.14	1.65	3.67	0.62	0.35
R03E9	5	2	5:1	rot	1.51	0.44	0.01	0.50	0.64
R03E9	6	2	10:1	rot	6.66	0.68	1.38	0.34	0.00
R03E9	7	2	5:1	ng	7.12	1.44	15.53	1.64	1.44
R03E9	8	2	10:1	ng	6.51	1.21	5.63	6.62	6.52
R03E9	9	2	NB	ng	1.67	0.38	3.79	0.28	0.20
R03E9	10	1	5:1	ng	8.33	4.10	0.00	25.24	19.15
R03E9	11	1	10:1	ng	6.51	1.11	6.52	1.03	1.23
R03E9	12	1	NB	ng	6.36	1.77	0.16	3.89	4.09
R03E9	13	1	5:1	con	5.11	1.21	7.06	1.36	1.32
R03E9	14	1	10:1	con	8.52	1.03	0.39	7.72	2.17
R03E9	15	1	NB	con	8.14	2.73	1.10	7.98	7.96
R03E9	16	1	10:1	rot	1.63	0.11	0.63	0.89	0.87
R03E9	17	1	5:1	rot	8.33	1.37	1.14	5.11	5.13
R03E9	18	1	NB	rot	11.58	4.40	12.89	4.84	3.85
R03E9	19	3	NB	rot	6.21	3.45	0.82	21.22	25.45
R03E9	20	3	5:1	rot	8.33	1.89	1.65	3.19	3.45
R03E9	21	3	10:1	rot					
R03E9	22	3	5:1	con	7.95	1.51	3.42	1.67	1.79
R03E9	23	3	10:1	con	1.70	0.29	0.80	0.27	0.27
R03E9	24	3	NB	con	1.85	0.47	0.18	0.30	0.33
R03E9	25	3	10:1	ng	2.04	0.45	0.51	0.16	0.29
R03E9	26	3	NB	ng					
R03E9	27	3	5:1	ng	1.97	0.53	0.61	0.15	0.72

Table A22. Raw data on runoff volume and total losses of sediment, NO_3-N, PO_4-P, and total-P from grazing and VFS buffer treatments for rainfall event 7-5-03E10 at the ISU Rhodes Research Farm site, central Iowa, USA.

ID	Sample	Plot	Buffer ratio	Grazing practice	Runoff L	Solids g	NO_3-N mg	PO_4-P mg	Total-P mg
R03E10	1	2	10:1	con	8.78	1.51	33.49	24.59	25.47
R03E10	2	2	NB	con	3.41	0.23	5.80	3.11	3.10
R03E10	3	2	5:1	con	3.71	0.44	21.96	7.69	7.79
R03E10	4	2	NB	rot	39.06	4.11	27.81	3.28	4.30
R03E10	5	2	5:1	rot	1.51	0.34	9.14	4.58	4.69
R03E10	6	2	10:1	rot	1.67	0.26	6.45	0.92	1.07
R03E10	7	2	5:1	ng	10.67	2.44	93.85	16.51	16.33
R03E10	8	2	10:1	ng	4.88	0.35	17.22	1.71	1.95
R03E10	9	2	NB	ng	9.99	1.95	81.49	16.44	16.09
R03E10	10	1	5:1	ng	9.99	0.83	17.87	7.13	6.59
R03E10	11	1	10:1	ng	11.39	2.22	61.07	15.27	14.58
R03E10	12	1	NB	ng	6.36	0.40	9.58	2.26	2.73
R03E10	13	1	5:1	con	6.81	0.77	14.65	7.13	6.68
R03E10	14	1	10:1	con	13.63	4.53	105.92	85.63	87.21
R03E10	15	1	NB	con	87.89	13.13	136.52	90.78	84.37
R03E10	16	1	10:1	rot	40.69	3.23	38.85	29.24	28.48
R03E10	17	1	5:1	rot	114.91	8.60	93.92	68.38	67.80
R03E10	18	1	NB	rot	11.58	1.20	8.18	3.32	3.59
R03E10	19	3	NB	rot	251.40	17.33	84.02	122.36	115.64
R03E10	20	3	5:1	rot	58.29	11.61	66.32	45.86	47.80
R03E10	21	3	10:1	rot	0.00	0.00			
R03E10	22	3	5:1	con	57.23	8.55	98.60	23.57	26.33
R03E10	23	3	10:1	con	27.25	4.12	15.80	14.13	14.72
R03E10	24	3	NB	con	27.82	5.09	41.37	13.40	14.74
R03E10	25	3	10:1	ng	6.13	0.58	8.81	7.27	6.87
R03E10	26	3	NB	ng	3.48	0.35	1.91	1.44	1.64
R03E10	27	3	5:1	ng	9.84	3.05	3.22	37.75	37.40

Table A23. Raw data on runoff volume and total losses of sediment, NO_3-N, PO_4-P, and total-P from grazing and VFS buffer treatments for rainfall event 9-12-03E11 at the ISU Rhodes Research Farm site, central Iowa, USA.

ID	Sample	Plot	Buffer ratio	Grazing practice	Runoff L	Solids g	NO_3-N mg	PO_4-P mg	Total-P mg
R03E11	1	2	10:1	con	8.78	1.44	2.56	26.71	7.20
R03E11	2	2	NB	con	1.70	0.11	0.49	2.33	2.16
R03E11	3	2	5:1	con	1.85	0.35	0.67	8.02	9.16
R03E11	4	2	NB	rot	3.26	2.73	0.00	35.90	38.87
R03E11	5	2	5:1	rot	1.51	0.47	5.16	8.25	7.93
R03E11	6	2	10:1	rot	1.67	0.98	0.12	19.68	20.40
R03E11	7	2	5:1	ng	3.56	0.36	2.90	4.84	4.77
R03E11	8	2	10:1	ng	6.51	0.49	7.23	3.02	3.19
R03E11	9	2	NB	ng	6.66	9.31	182.59	145.02	151.22
R03E11	10	1	5:1	ng	1.67	0.16	4.20	1.48	1.60
R03E11	11	1	10:1	ng	1.63	0.10	4.16	0.60	0.68
R03E11	12	1	NB	ng	1.59	0.08	0.57	0.32	0.32
R03E11	13	1	5:1	con	1.70	1.16	2.39	9.18	10.29
R03E11	14	1	10:1	con	1.70	1.20	0.00	12.06	13.86
R03E11	15	1	NB	con	22.79	2.03	9.41	24.94	25.52
R03E11	16	1	10:1	rot	1.63	0.15	3.72	1.53	1.59
R03E11	17	1	5:1	rot	9.99	1.53	42.90	21.82	27.38
R03E11	18	1	NB	rot	1.93	0.07	0.34	0.28	0.23
R03E11	19	3	NB	rot	150.53	8.06	60.88	77.11	73.76
R03E11	20	3	5:1	rot	6.66	0.42	0.86	1.33	1.93
R03E11	21	3	10:1	rot	12.72	1.30	7.23	12.45	12.34
R03E11	22	3	5:1	con	3.18	0.34	0.68	0.62	1.05
R03E11	23	3	10:1	con	1.70	0.44	2.05	5.04	6.18
R03E11	24	3	NB	con	1.85	0.46	0.07	5.80	7.29
R03E11	25	3	10:1	ng	2.04	1.26	0.00	4.98	7.42
R03E11	26	3	NB	ng	3.48	5.46	0.00	12.57	19.95
R03E11	27	3	5:1	ng	0.00				

Table A24. Raw data on runoff volume and total losses of sediment, NO_3-N, PO_4-P, and total-P from grazing and VFS buffer treatments for rainfall event 11-4-03E12 at the ISU Rhodes Research Farm site, central Iowa, USA.

ID	Sample	Plot	Buffer ratio	Grazing practice	Runoff L	Solids g	NO_3-N mg	PO_4-P mg	Total-P mg
R03E12	1	2	10:1	con	2.20	0.37	0.75	3.26	2.90
R03E12	2	2	NB	con	21.12	0.52	3.80	2.58	2.11
R03E12	3	2	5:1	con	7.42	3.41	0.52	148.02	128.64
R03E12	4	2	NB	rot	24.41	3.35	206.05	64.13	70.07
R03E12	5	2	5:1	rot	3.03	0.42	4.42	1.68	18.38
R03E12	6	2	10:1	rot	8.33	0.91	6.58	14.49	13.41
R03E12	7	2	5:1	ng	0.00	0.00			
R03E12	8	2	10:1	ng	154.62	31.57	615.38	109.66	120.60
R03E12	9	2	NB	ng	84.94	20.55	158.83	40.96	40.77
R03E12	10	1	5:1	ng	3.33	0.35	2.53	2.09	2.07
R03E12	11	1	10:1	ng	402.00	69.13	309.54	64.70	88.44
R03E12	12	1	NB	ng	384.71	91.18	111.57	47.57	73.09
R03E12	13	1	5:1	con	5.11	0.50	1.99	2.95	2.81
R03E12	14	1	10:1	con	20.44	3.62	13.90	16.60	14.51
R03E12	15	1	NB	con	841.44	153.87	92.56	885.27	790.96
R03E12	16	1	10:1	rot	1334.59	138.33	200.19	708.38	693.99
R03E12	17	1	5:1	rot	577.89	69.34	104.02	244.08	231.16
R03E12	18	1	NB	rot	3.86	0.66	0.35	0.95	0.50
R03E12	19	3	NB	rot	1180.96	187.11	165.33	309.71	389.72
R03E12	20	3	5:1	rot	481.30	60.01	52.94	117.72	110.70
R03E12	21	3	10:1	rot	743.98	84.92	193.43	246.50	252.95
R03E12	22	3	5:1	con	246.40	27.39	46.82	95.18	93.63
R03E12	23	3	10:1	con	318.51	28.52	41.41	115.70	114.66
R03E12	24	3	NB	con	79.75	13.83	10.37	15.17	13.56
R03E12	25	3	10:1	ng	3599.31	624.38	755.85	349.75	539.90
R03E12	26	3	NB	ng	1211.81	151.35	206.01	131.12	133.30
R03E12	27	3	5:1	ng					

APPENDIX B

RAW DATA FOR WINDROW COMPOSTING SITE SEDIMENT AND NUTRIENT CONCENTRATIONS AND TOTAL LOSSES WITH RUNOFF

Table B1. Raw data on runoff depth and concentrations of sediment, NO_3-N, PO_4-P, and total-P from windrow composting and VFS buffer treatments for rainfall event 8-5-02E1 at the ISU Dairy Teaching Farm site, Ames, Iowa, USA.

ID	Sample	Block	Treatment	Buffer ratio	Runoff mm	Solids g/kg	NO_3-N mg/L	PO_4-P mg/L	Total-P mg/L
D02E1	1	1	3	1:1	0.29	0.88		0.7	0.80
D02E1	2	1	2	1:0.5	0.36	0.95	0.07	3.1	4.20
D02E1	3	1	1	1:0	21.29	2.62	0.18	4.5	3.05
D02E1	4	2	2	1:0.5	8.00	1.15	0.08	2.4	4.90
D02E1	5	2	1	1:0	32.76	2.03	0.17	3.1	4.20
D02E1	6	2	3	1:1		1.69	0.02	1.5	1.90
D02E1	7	3	2	1:0.5	0.12	0.68	0.03	2.7	3.60
D02E1	8	3	3	1:1	1.59	0.93	0.05	2.3	3.40
D02E1	9	3	1	1:0	13.16	3.51	0.47	5.9	5.45

Table B2. Raw data on runoff percent of rainfall, runoff volume, and total losses of sediment, NO_3-N, PO_4-P, and total-P from windrow composting and VFS buffer treatments for rainfall event 8-5-02E1 at the ISU Dairy Teaching Farm site, Ames, Iowa, USA.

ID	Sample	Block	Buffer	Runoff	Runoff	Solids	NO_3-N	PO_4-P	Total-P
			ratio	%rainfall	L	g	mg	mg	mg
D02E1	1	1	1:1	0.83	66.43	58.46		48.72	53.14
D02E1	2	1	1:0.5	1.03	61.85	58.88	4.13	192.29	259.76
D02E1	3	1	1:0	60.83	2417.93	6336.28	437.94	10973.23	7374.70
D02E1	4	2	1:0.5	22.86	1362.49	1562.30	107.40	3217.73	6676.18
D02E1	5	2	1:0	93.60	3719.90	7545.26	630.68	11707.44	15623.57
D02E1	6	2	1:1		0.00				
D02E1	7	3	1:0.5	0.34	21.20	14.47	0.55	57.58	76.31
D02E1	8	3	1:1	4.54	361.62	335.51	19.84	844.80	1229.50
D02E1	9	3	1:0	37.60	1493.86	5238.08	695.39	8863.56	8141.56

Table B3. Raw data on runoff depth and concentrations of sediment, NO_3-N, PO_4-P, and total-P from windrow composting and VFS buffer treatments for rainfall event 6-25-03E2 at the ISU Dairy Teaching Farm site, Ames, Iowa, USA.

ID	Sample	Block	Treatment	Buffer ratio	Runoff mm	Solids g/kg	NO_3-N mg/L	PO_4-P mg/L	Total-P mg/L
D03E2	1	1	3	1:1	0.01	1.78	23.51	4.29	4.91
D03E2	2	1	2	1:0.5	1.06	1.69	21.84	2.44	3.10
D03E2	3	1	1	1:0	11.44	2.07	27.17	3.41	4.29
D03E2	4	2	2	1:0.5	9.18	1.51	21.21	2.49	3.10
D03E2	5	2	1	1:0	28.30	6.43	58.82	7.34	8.00
D03E2	6	2	3	1:1	0.16	1.82	23.07	3.90	4.97
D03E2	7	3	2	1:0.5		1.57	21.14	3.71	4.86
D03E2	8	3	3	1:1	0.07	1.30	0.07	15.19	8.00
D03E2	9	3	1	1:0	56.03	2.35	26.57	3.41	5.25

Table B4. Raw data on runoff depth and concentrations of sediment, NO_3-N, PO_4-P, and total-P from windrow composting and VFS buffer treatments for rainfall event 7-5-03E3 at the ISU Dairy Teaching Farm site, Ames, Iowa, USA.

ID	Sample	Block	Treatment	Buffer ratio	Runoff mm	Solids g/kg	NO_3-N mg/L	PO_4-P mg/L	Total-P mg/L
D03E3	1	1	3	1:1	0.00	1.38	8.81	2.99	3.13
D03E3	2	1	2	1:0.5	0.00	1.70	15.66	2.41	2.97
D03E3	3	1	1	1:0	21.89	2.29	18.89	3.00	3.80
D03E3	4	2	2	1:0.5	13.35	1.80	17.96	1.85	2.46
D03E3	5	2	1	1:0	26.90	4.52	29.64	7.76	8.00
D03E3	6	2	3	1:1	5.75	1.86	11.66	2.19	3.15
D03E3	7	3	2	1:0.5	0.01	1.48	10.42	3.89	4.27
D03E3	8	3	3	1:1	0.02				
D03E3	9	3	1	1:0	47.93	2.30	17.86	2.30	3.18

Table B5. Raw data on runoff percent of rainfall, runoff volume, and total losses of sediment, NO_3-N, PO_4-P, and total-P from windrow composting and VFS buffer treatments for rainfall event 6-25-03E2 at the ISU Dairy Teaching Farm site, Ames, Iowa, USA.

ID	Sample	Block	Buffer ratio	Runoff %rainfall	Runoff L	Solids g	NO_3-N mg	PO_4-P mg	Total-P mg
D03E2	1	1	1:1	0.01	1.48	2.63	34.71	6.33	7.25
D03E2	2	1	1:0.5	1.31	179.79	304.11	3926.32	439.09	557.01
D03E2	3	1	1:0	14.12	1299.01	2689.67	35291.02	4428.58	5570.78
D03E2	4	2	1:0.5	11.33	1563.24	2358.38	33163.70	3893.29	4843.15
D03E2	5	2	1:0	34.94	3213.47	20645.02	189005.84	23574.85	25707.72
D03E2	6	2	1:1	0.20	36.34	65.92	838.37	141.63	180.71
D03E2	7	3	1:0.5		0.00				
D03E2	8	3	1:1	0.09	15.44	19.99	1.03	234.65	123.54
D03E2	9	3	1:0	69.17	6362.21	14961.06	169053.67	21675.27	33404.97

Table B6. Raw data on runoff percent of rainfall, runoff volume, and total losses of sediment, NO_3-N, PO_4-P, and total-P from windrow composting and VFS buffer treatments for rainfall event 7-5-03E3 at the ISU Dairy Teaching Farm site, Ames, Iowa, USA.

ID	Sample	Block	Buffer ratio	Runoff %rainfall	Runoff L	Solids g	NO_3-N mg	PO_4-P mg	Total-P mg
D03E3	1	1	1:1	0.00	0.00	0.00	0.00	0.00	0.00
D03E3	2	1	1:0.5	0.00	0.00	0.00	0.00	0.00	0.00
D03E3	3	1	1:0	35.89	2485.84	5681.71	46959.53	7469.69	9444.43
D03E3	4	2	1:0.5	21.89	2273.27	4082.31	40823.71	4198.42	5597.26
D03E3	5	2	1:0	44.10	3054.50	13780.56	90538.38	23693.63	24435.96
D03E3	6	2	1:1	9.43	1305.07	2430.38	15211.05	2864.38	4107.12
D03E3	7	3	1:0.5	0.02	1.32	1.96	13.81	5.15	5.66
D03E3	8	3	1:1	0.03	3.86	0.00	0.00	0.00	0.00
D03E3	9	3	1:0	78.57	5442.57	12484.33	97218.68	12540.69	17305.56

Table B7. Raw data on runoff depth and concentrations of sediment, NO_3-N, PO_4-P, and total-P from windrow composting and VFS buffer treatments for rainfall event 7-3-04E4 at the ISU Dairy Teaching Farm site, Ames, Iowa, USA.

ID	Sample	Block	Treatment	Buffer	Runoff	Solids	NO_3-N	PO_4-P	Total-P
				ratio	mm	g/kg	mg/L	mg/L	mg/L
D04E4	1	1	3	1:1	0.01	0.50	0.07	4.02	4.54
D04E4	2	1	2	1:0.5	0.01		0.41	23.87	17.44
D04E4	3	1	1	1:0	2.63	2.11	19.05	1.51	3.14
D04E4	4	2	2	1:0.5		1.49	0.01	1.36	2.84
D04E4	5	2	1	1:0	1.72	2.87	6.14	1.45	3.04
D04E4	6	2	3	1:1	0.01	0.19	0.94	2.64	2.94
D04E4	7	3	2	1:0.5	0.01	1.27	0.05	3.97	0.95
D04E4	8	3	3	1:1	0.01	0.57	0.01	5.48	6.24
D04E4	9	3	1	1:0	2.81	2.72	0.02	1.43	1.50

Table B8. Raw data on runoff depth and concentrations of sediment, NO_3-N, PO_4-P, and total-P from windrow composting and VFS buffer treatments for rainfall event 8-26-04E5 at the ISU Dairy Teaching Farm site, Ames, Iowa, USA.

ID	Sample	Block	Treatment	Buffer ratio	Runoff mm	Solids g/kg	NO_3-N mg/L	PO_4-P mg/L	Total-P mg/L
D04E5	1	1	3	1:1	0.08	0.77	18.51	9.40	13.54
D04E5	2	1	2	1:0.5	0.04				
D04E5	3	1	1	1:0	3.24	2.78	28.71	2.55	3.94
D04E5	4	2	2	1:0.5	0.08	0.79	21.40	7.89	10.14
D04E5	5	2	1	1:0	3.84	2.05	20.40	1.87	3.14
D04E5	6	2	3	1:1	0.05	0.48	27.56	3.99	6.04
D04E5	7	3	2	1:0.5	0.02				
D04E5	8	3	3	1:1	0.01				
D04E5	9	3	1	1:0	3.86	1.33	29.33	3.27	5.24

Table B9. Raw data on runoff depth and concentrations of sediment, NO_3-N, PO_4-P, and total-P from windrow composting and VFS buffer treatments for rainfall event 9-6-04E6 at the ISU Dairy Teaching Farm site, Ames, Iowa, USA.

ID	Sample	Block	Treatment	Buffer ratio	Runoff mm	Solids g/kg	NO_3-N mg/L	PO_4-P mg/L	Total-P mg/L
D04E6	1	1	3	1:1	0.01	0.85	19.28	12.78	15.35
D04E6	2	1	2	1:0.5	0.02	1.14	20.73	16.79	18.70
D04E6	3	1	1	1:0	8.65	2.38	51.83	4.37	5.85
D04E6	4	2	2	1:0.5	0.01	0.56		10.21	14.45
D04E6	5	2	1	1:0	6.48	1.73	35.87	2.11	3.05
D04E6	6	2	3	1:1	0.04	0.38	15.81	6.09	7.05
D04E6	7	3	2	1:0.5	0.02	0.81	11.40	12.74	17.45
D04E6	8	3	3	1:1	0.01				
D04E6	9	3	1	1:0	4.52	4.18	83.89	3.88	5.45

Table B10. Raw data on runoff percent of rainfall, runoff volume, and total losses of sediment, NO_3-N, PO_4-P, and total-P from windrow composting and VFS buffer treatments for rainfall event 7-3-04E4 at the ISU Dairy Teaching Farm site, Ames, Iowa, USA.

ID	Sample	Block	Buffer ratio	Runoff %rainfall	Runoff L	Solids g	NO_3-N mg	PO_4-P mg	Total-P mg
D04E4	1	1	1:1	0.02	1.48	0.74	0.10	5.94	6.70
D04E4	2	1	1:0.5	0.02	1.44	0.00	0.59	34.34	25.08
D04E4	3	1	1:0	5.72	298.18	629.93	5679.27	451.27	936.29
D04E4	4	2	1:0.5	0.00	0.00	0.00	0.00	0.00	0.00
D04E4	5	2	1:0	3.74	195.31	560.91	1198.79	283.03	593.73
D04E4	6	2	1:1	0.02	1.51	0.28	1.42	3.99	4.45
D04E4	7	3	1:0.5	0.02	1.32	1.69	0.07	5.25	1.26
D04E4	8	3	1:1	0.02	1.29	0.73	0.01	7.06	8.03
D04E4	9	3	1:0	6.11	318.85	867.53	6.59	456.82	478.27

Table B11. Raw data on runoff percent of rainfall, runoff volume, and total losses of sediment, NO_3-N, PO_4-P, and total-P from windrow composting and VFS buffer treatments for rainfall event 8-26-04E5 at the ISU Dairy Teaching Farm site, Ames, Iowa, USA.

ID	Sample	Block	Buffer	Runoff	Runoff	Solids	NO_3-N	PO_4-P	Total-P
			ratio	%rainfall	L	g	mg	mg	mg
D04E5	1	1	1:1	0.24	17.71	13.72	327.85	166.43	239.84
D04E5	2	1	1:0.5	0.12	7.19	0.00			
D04E5	3	1	1:0	9.82	367.56	1021.95	10550.86	938.78	1448.19
D04E5	4	2	1:0.5	0.24	13.29	10.45	284.30	104.81	134.71
D04E5	5	2	1:0	11.64	436.03	892.77	8894.97	814.55	1369.14
D04E5	6	2	1:1	0.15	10.60	5.13	292.04	42.31	64.01
D04E5	7	3	1:0.5	0.06	2.65				
D04E5	8	3	1:1	0.03	2.57				
D04E5	9	3	1:0	11.70	438.42	582.99	12860.20	1433.16	2297.30

Table B12. Raw data on runoff percent of rainfall, runoff volume, and total losses of sediment, NO_3-N, PO_4-P, and total-P from windrow composting and VFS buffer treatments for rainfall event 9-6-04E6 at the ISU Dairy Teaching Farm site, Ames, Iowa, USA.

ID	Sample	Block	Buffer	Runoff	Runoff	Solids	NO_3-N	PO_4-P	Total-P
			ratio	%rainfall	L	g	mg	mg	mg
D04E6	1	1	1:1	0.02	1.48	1.25	28.46	18.87	22.66
D04E6	2	1	1:0.5	0.04	2.88	3.29	59.65	48.29	53.79
D04E6	3	1	1:0	18.80	981.64	2336.64	50876.61	4289.79	5742.59
D04E6	4	2	1:0.5	0.02	1.48	0.83	0.00	15.07	21.33
D04E6	5	2	1:0	14.09	735.80	1269.55	26393.18	1549.04	2244.20
D04E6	6	2	1:1	0.09	9.08	3.45	143.63	55.36	64.04
D04E6	7	3	1:0.5	0.04	2.65	2.14	30.20	33.75	46.23
D04E6	8	3	1:1	0.02	1.29				
D04E6	9	3	1:0	9.83	513.70	2145.94	43093.78	1995.72	2799.67

APPENDIX C

RAW DATA FOR WINDROW COMPOSTING SITE RUNOFF HYDROLOGIC MODELING

Table C1. Raw data on weather parameter input data for WCVFS model calibration simulations from windrow composting and VFS buffer treatments for rainfall event 8-5-02E1EEC at the ISU Dairy Teaching Farm site, Ames, Iowa, USA.

t	year	month	day	Tmax	Tmin	precip	dewpoint	potevt	dailyevap	evapcoeff
1	2002	7	26	87.2	66.5	0	70.9	0.186	0.2	0.78
2	2002	7	27	90.4	67.5	0	64.1	0.205	0.31	0.78
3	2002	7	28	89	70.8	0	61.5	0.193	0.25	0.78
4	2002	7	29	86.6	67.2	0	65.7	0.265	0.27	0.78
5	2002	7	30	92.1	65.3	0	64	0.311	0.34	0.78
6	2002	7	31	91.1	69.2	0	61.1	0.322	0.4	0.78
7	2002	8	1	86.7	59.4	0	54.1	0.31	0.42	0.78
8	2002	8	2	78	52.7	0	58.7	0.246	0.38	0.78
9	2002	8	3	89.6	57.4	0	60.8	0.255	0.19	0.78
10	2002	8	4	83.6	69.1	0	56.5	0.15	0.28	0.78
11	2002	8	5	82.9	69.7	1.4	52.8	0.121	0.13	0.78
12	2002	8	6	75.8	63	0	58.1	0.115	0.32	0.78

Table C2. Raw data on weather parameter input data for WCVFS model calibration simulations from windrow composting and VFS buffer treatments for rainfall event 6-25-03E2EEC at the ISU Dairy Teaching Farm site, Ames, Iowa, USA.

t	year	month	day	Tmax	Tmin	precip	dewpoint	potevt	dailyevap	evapcoeff
1	2003	6	15	84.7	61.8	0	54.4	0.247	0.44	0.78
2	2003	6	16	86.2	64.6	0	51.7	0.272	0.24	0.78
3	2003	6	17	85.8	61.6	0	62.1	0.207	0.31	0.78
4	2003	6	18	85.1	66.8	0	69.6	0.206	0.15	0.78
5	2003	6	19	78.7	58.3	0	68.3	0.32	0.46	0.78
6	2003	6	20	77.8	51.5	0	63.9	0.322	0.47	0.78
7	2003	6	21	81.4	55.1	0	61.4	0.305	0.38	0.78
8	2003	6	22	85.8	61.2	0	59.3	0.26	0.33	0.78
9	2003	6	23	88.4	70.5	0	66.2	0.31	0.41	0.78
10	2003	6	24	92.4	65.7	0	68.7	0.31	0.44	0.78
11	2003	6	25	78.7	58.6	3.2	62.9	0.055	0.27	0.78
12	2003	6	26	72	52.1	0	52.9	0.251	0.19	0.78

Table C3. Raw data on weather parameter input data for WCVFS model validation simulation from windrow composting and VFS buffer treatments for rainfall event 7-5-03E3EEV at the ISU Dairy Teaching Farm site, Ames, Iowa, USA.

t	year	month	day	Tmax	Tmin	precip	dewpoint	potevt	dailyevap	evapcoeff
1	2003	6	25	78.7	58.6	0	62.9	0.055	0.27	0.78
2	2003	6	26	72	52.1	0	52.9	0.251	0.19	0.78
3	2003	6	27	83.4	53.6	0	60.3	0.28	0.27	0.78
4	2003	6	28	80	59.5	0	64	0.254	0.46	0.78
5	2003	6	29	79.9	60.4	0	65.1	0.227	0.31	0.78
6	2003	6	30	82.8	58.4	0	68.2	0.248	0.17	0.78
7	2003	7	1	83.5	62.4	0	65.7	0.252	0.45	0.78
8	2003	7	2	87.3	63.5	0	68	0.292	0.26	0.78
9	2003	7	3	93.6	71.3	0	71.5	0.316	0.3	0.78
10	2003	7	4	84.8	64.1	0	72.4	0.212	0.35	0.78
11	2003	7	5	83.5	63.2	2.4	68.7	0.233	0.67	0.78
12	2003	7	6	86.3	64.8	0	64.5	0.256	0.44	0.78

Table C4. Raw data on weather parameter input data for WCVFS model calibration simulations from windrow composting and VFS buffer treatments for rainfall event 7-3-04E4LEC at the ISU Dairy Teaching Farm site, Ames, Iowa, USA.

t	year	month	day	Tmax	Tmin	precip	dewpoint	potevt	dailyevap	evapcoeff
1	2004	6	23	79.7	58.0	0	65	0.285	0.31	0.78
2	2004	6	24	60.9	48.4	0	61.3	0.098	0.24	0.78
3	2004	6	25	72.1	42.7	0	64.4	0.247	0.16	0.78
4	2004	6	26	76.5	49.3	0	61.1	0.248	0.25	0.78
5	2004	6	27	74	57.1	0	63.9	0.128	0.29	0.78
6	2004	6	28	75	51.9	0	58.2	0.245	0.18	0.78
7	2004	6	29	79.1	53.1	0	57.9	0.256	0.29	0.78
8	2004	6	30	80	54.0	0	62	0.265	0.23	0.78
9	2004	7	1	85.1	60.9	0	65.5	0.258	0.38	0.78
10	2004	7	2	78.4	67.3	0	63.2	0.11	0.28	0.78
11	2004	7	3	73	64.6	1.8	63.7	0.064	0.21	0.78
12	2004	7	4	83.2	62.8	0	71.5	0.235	0.14	0.78

Table C5. Raw data on weather parameter input data for WCVFS model calibration simulations from windrow composting and VFS buffer treatments for rainfall event 8-26-04E5LEC at the ISU Dairy Teaching Farm site, Ames, Iowa, USA.

t	year	month	day	Tmax	Tmin	precip	dewpoint	potevt	dailyevap	evapcoeff
1	2004	8	16	77.7	54.1	0	59	0.186	0.23	0.78
2	2004	8	17	76.4	59.5	0	64	0.148	0.28	0.78
3	2004	8	18	72.5	52.3	0	64.7	0.061	0.35	0.78
4	2004	8	19	66.4	45.3	0	63.6	0.169	0.03	0.78
5	2004	8	20	74.4	48.7	0	57	0.181	0.15	0.78
6	2004	8	21	72.8	48.3	0	55.3	0.192	0.32	0.78
7	2004	8	22	81.2	59.7	0	57.7	0.218	0.22	0.78
8	2004	8	23	82.2	64.5	0	61.7	0.139	0.22	0.78
9	2004	8	24	77.2	64.0	0	63	0.123	0.15	0.78
10	2004	8	25	76.5	62.3	0	67.1	0.085	0.12	0.78
11	2004	8	26	84.6	65.0	1.3	66	0.161	0.18	0.78
12	2004	8	27	80	61.6	0	70.7	0.206	0.39	0.78

Table C6. Raw data on weather parameter input data for WCVFS model validation simulation from windrow composting and VFS buffer treatments for rainfall event 9-6-04E6LEV at the ISU Dairy Teaching Farm site, Ames, Iowa, USA.

t	year	month	day	Tmax	Tmin	precip	dewpoint	potevt	dailyevap	evapcoeff
1	2004	8	27	80	61.6	0	70.7	0.206	0.39	0.78
2	2004	8	28	72.2	56.3	0	56.8	0.137	0.31	0.78
3	2004	8	29	72.9	51.9	0	54.5	0.149	0.14	0.78
4	2004	8	30	79.8	56.2	0	63.4	0.224	0.15	0.78
5	2004	8	31	81.3	54.0	0	52.2	0.194	0.32	0.78
6	2004	9	1	86.2	62.7	0	49.6	0.216	0.14	0.78
7	2004	9	2	81.3	60.0	0	49.6	0.202	0.42	0.78
8	2004	9	3	81.6	57.5	0	54.2	0.199	0.16	0.78
9	2004	9	4	83.4	60.2	0	60.1	0.192	0.24	0.78
10	2004	9	5	82	63.7	0	60.1	0.148	0.27	0.78
11	2004	9	6	75.2	55.4	1.8	53.8	0.26	0.43	0.78
12	2004	9	7	70.4	48.7	0	54.8	0.194	0.29	0.78

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